UNIVERSITY OF KHARTOUM
FACULTY OF ENGINEERING AND ARCHITECTURE
ELECTRICAL AND ELECTRONICS DEPT.

MW FLOW STATE ESTIMATOR FOR THE NATIONAL GRID

A thesis submitted for partial Fulfillment of the requirements of the Degree of Master in power Engineering

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بسم ا   الرحمن الرحيم

اقرأ باسم ربك الذي خلق () خلق الإنسان من علق() اقرأ

و ربك الأكرم() الذي علم بالقلم ()

علم الإنسان ما لم يعلم.

صدق ا   العظيم

DEDICATION

I would like to dedicate this Thesis

To

My family

My Friends

And

Colleagues

Rehab

ACKNOWLEDGMENT

I would like to extend my special thanks to my supervisor
Dr. Abdelrahman Karrar
For the time he has devoted to me during my research on this thesis.

I would like to extend my great, special thanks and appreciation to
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My Aunt Ustaz.Suhair Mahdi
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Any one extend his help hand *during my research on this thesis*

Abstract

As telemetering and SCADA applications are increasingly being employed by the National Grid dispatch center, it would be productive to assess the integrity of the data flow from remote measuring points. It is inevitable that errors would creep in due to a variety of factors ranging from flawed meters to a noisy communication channel.

The objective of this project is to setup a state estimator to correlate the mw flow readings using DC flow methods in conjunction with a weighted -least-square estimator.

The work is done inclusively on computer simulation using *MATLAB* language and *LOAD FLOW* program. It consists of four stages: -

1st stage: the mw flow in National Grid (NG) transmission lines.

2nd stage: the mw flow after a shift in generation output.

3rd stage: the mw flow after an outage of line.

4th stage: the mw flow state estimator for the three stages above.

ملخص البحث

من المفيد تقييم سلامة وكمال سريان البيانات من النقاط المقاسة بعيدا لأنه حتما سوف تكون هنالك أخطاء ناتجة من عوامل متنوعة و ذلك في المسافة من العدادات المتصدعة وحتى قنوات الاتصال المتأثرة بالضجيج .

يهدف هذا المشروع إلى إعداد مقيم حالة يرتبط مع قراءة تدفق قدرة (MW) باستعمال طرق سريان قدرة (MW) المقترنة مع مقيم المربعات- ذات الأوزان- الصغرى.

تركز العمل علي برنامج كمبيوتر بلغة MATLAB ، وبرنامج LOADFLOW لمقارنة النتائج. تضمن البرنامج أربعة مراحل:

<u>المرحلة الأولى</u>

تدفق قدرة(MW) في الشبكة القومية.

<u>المرحلة الثانية</u>

تدفق قدرة (MW) في الشبكة القومية بعد التغير في خرج أحد المولدات.

<u>المرحلة الثالثة</u>

تدفق قدرة (MW) في الشبكة القومية بعد انقطاع (خسارة) أحد خطوط النقل.

<u>المرحلة الرابعة</u>

مقيم حالة تدفق قدرة(MW) للثلاث مراحل أعلاه.

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CHAPTER ONE

INTRODUCTION

1 INTRODUCTION

The problem of monitoring power flows on a transmission system is very important in maintaining system security. By simply checking each measured value against its limit, corrective actions could be taken.

Many problems are encountered in monitoring a transmission system. These problems come primarily from the nature of the measurement transducers and from communication problems in transmitting the measured values back. Transducers for power system measurements, like any measurement device, will be subject to errors, also the telemetry equipment often experiences periods when communication channels are completely out, thus depriving the system operator of any information about some part of the power system network.

It is for these reasons that state estimation techniques have been developed. A state estimator can "smooth out" small random errors in meter readings, detect and identify gross measurements errors, and "fill in" meter readings that have failed due to communications failures.

In general, the state variables for a power system consist of the bus voltage magnitude at all buses and the phase angles at all but one bus. The swing or reference bus phase angle is usually assumed to be zero radians. If measurements can be used to estimate the "states" i. e phase angles in our case of the power system, then calculating any power flows, generation and loads can be done.

1.1 Problem Definition

To estimate and correct measured data on power systems, the National Grid system is used as a model to calculate the Mw flows on its transmission lines, the effect of changes of generation outputs and the effect of line outages. Hence setting up a state estimator to correlate these readings using dc flow methods in conjunction with a weighted-least-square estimator.

1.2 Method Adopted

The analysis is done by means of computer programming using MATLAB, which is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. The basic data element is an array that does not require dimensioning. This allows solving many technical-computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a language such as C or Fortran.

The data is prepared in EXCEL file and imported to MATLAB by means of EXCEL link function called (xlsread).

1.3 Thesis Layout

This thesis has been organized in six chapters and the following are the main aspects of each of these chapters:

- Chapter one presents an introduction.
- Chapter two presents DC power flow.

  In this chapter the DC power flow and linear sensitivity factors were discussed.
- Chapter three presents state estimation in power systems.

  In this Chapter power systems state estimation, Weighted Least Squares Estimation and Estimation of Quantities Not Being Measured are discussed.
- Chapter four presents description of the NG System.
- Chapter five presents application and results.
- Chapter six presents conclusions and recommendations.

CHAPTER TWO

DC POWER FLOW

2 D.C Power Flow

2.1 D.C Power Flow

D.C. power flow is only good for calculating MW flows on transmission lines and transformers. It gives no indication of what happens to voltage magnitudes or MVAR or MVA flows.

It governed by the simple relation: -

$$[\Delta P]=[B`].\,[\Delta\theta] \qquad (2.1)$$

Where

$[\Delta p]$ Is a vector representing the net mw quantities at the busbars.

$[\Delta\theta]$ Is a vector representing the phase angles in radians

$[B`]$ Is the suceptance matrix, and is evaluated as follows: -

$$b_{ik}= -1/x_{ik} \qquad (2.2)$$

$$b_{ii} =\sum_{k=1}^{N} 1/x_{ik} \qquad (2.3)$$

Where x_{ik} is the reactance of line (i, k).

Now the power flow in each line using the D.C power flow is then: -

$$\Delta P_{ik}= (\theta_i-\theta_k)/x_{ik}$$

$$\Delta P_{ik} = -b_{ik}(\theta_i-\theta_k) \qquad (2.4)$$

2.2 Sensitivity Factors

One of the easiest ways to provide quick calculations of possible overloads is to use linear sensitivity factors.

The sensitivity factors show the approximate changes in line flows for changes in generation and network configuration.

There factors are of two types: -

1\ generation shift factor ($a_{l,i}$).

2\ line outage distribution factor ($d_{l,k}$).

2.2.1 The Generation Shift Factor

This Factor has the following definition: -

$$a_{l\,i} = \Delta f_l / \Delta p_i \qquad (2.5)$$

where: -

l is the line index.

i is the bus index.

Δp_i = the change in generation at bus i.

Δf_l = the change in megawatt power flow on line l when a change in generation Δp_i, occur at bus i.

The al i factor then represents the sensitivity of the flow on line l to achange in generation at bus i. If a generator at bus i was generating p_i^{o} Mw and it was lost ,Δp_i would be represented as

$$\Delta p_i = -p_i^{o} \qquad (2.6)$$

The new power flow on each line in the network can be calculated using a pre-calculated set of "a" factors as follows: -

$$f_l^{n} = f_l^{o} + a_{l\,i}\,\Delta p_i \qquad (2.7)$$

Where

f_l^{n} = the flow on line l after the generator on bus I fail.

f_l^{o} = the flow before the failure.

The generation shift sensitivity factor is a linear estimate of the change in flow with the change in power at a bus. Therefore the effect of simultaneous changes on several generating buses can be calculated using superposition.

In general the generation shift factor can be represented as:

$$a_{l\,i} = (1/x_l).(X_{n\,i} - X_{m\,i}) \qquad (2.8).$$

Where

$X_{n\,i} = \Delta\,\theta_n / \Delta\,p_i$

$X_{m\,i} = \Delta\,\theta_m / \Delta\,p_i$

x_l is the line reactance

2.2.2 Line Outage Distribution Factor

The line outage distribution factor is used in a similar manner, but it is only applied when testing for overloads when transmission circuits are lost. By definition, the line outage distribution factor has the following meaning:

$$d_{l\,k} = \Delta f_{l} / f_k^{o} \qquad (2\text{-}9)$$

Where

$d_{l\,k}$ line outage distribution factor when monitoring line l after an outage of line k

Δf_{l} change in Mw flow on line l

f_k^{o} original flow on line k before it was outaged.

If the flows on line l and k are known, the flow on line l with line k out can be determined using "d" factors.

$$f_l^{n} = f_l^{o} + \Delta f_{l} \qquad (2.10)$$

$$f_l^{n} = f_l^{o} + d_{l\,k}\, f_k^{o} \qquad (2.11)$$

Where

f_l^{o} , f_k^{o} ≡ pre-outage flows on lines l and k respectively.

f_l^{n} ≡ flow on line l with line k out.

If the outaged line k is from bus n to bus m, line l is from bus i to bus j and neither i nor j is a reference bus,then the line outaged distribution factor can be represented as:

$$d_{l\,k} = \frac{1}{x_l}\left(\frac{(X_{in}-X_{im})x_k-(X_{jn}-X_{jm})x_k}{x_k-(X_{nn}+X_{mm}-2X_{nm})}\right) \qquad (2.12)$$

Where

[X]: is the inverse of the suceptance matrix [B`].

[x]: is a vector representing the line reactances.

CHAPTER THREE

STATE ESTIMATION IN POWER SYSTEMS

3 STATE ESTIMATION IN POWER SYSTEMS

3.1 Introduction

State estimation is the process of assigning a value to an unknown system state based on measurements from that system according to some criteria. It may be broadly divided into two categories, namely static and dynamic estimation.

Static methods are mainly applied in the determination of load flows in a transmission network where, the approximation of steady state over a short period of time, is adequate.

Dynamic state estimation on the other hand is normally associated with transient and dynamic stability problems where the dynamics of the elements of the system must be considered, and is typified by the integrated power plant control problem.

Usually the process involves imperfect measurements that are redundant and the process of estimating the system states is based on a statistical criterion that estimates the true values of the state variables to minimize or maximize the selected criterion.

A commonly used and familiar criterion is that of minimizing the sum of squares of the differences between the estimated and true values of a function. In a power system, the state variables are the voltage magnitudes and relative phase angles at the system nodes. Measurements are required in order to estimate the system performance in real time for both system security control and constraints on economic dispatch.

The inputs to an estimator are imperfect power system measurements. The estimator is designed to produce the best estimate of the system voltage and phase angles, recognizing that there are errors in the measured quantities and that there may be redundant measurements. The out put data are then used in system control in the implementation of the security-constrained dispatch and control of the system.

3.2 Maximum likelihood weighted least-squares estimation

Statistical estimation refers to a procedure where one uses samples to calculate the value of one or more unknown parameters in a system. Since the samples are inexact, the estimate obtained for the unknown parameter is also inexact. This leads to the problem of how to formulate a best estimate of the unknown parameters given the available measurements.

The development of the notions of state estimation may proceed along several lines, depending on the statistical criterion selected. Many criteria have been examined and used in various applications, the following three are perhaps the most commonly encountered.

The maximum likelihood criterion, where the objective is to maximize the probability that the estimate of the state variable, $\hat{x}$, is the true value of the state variable vector, x (maximize p ($\hat{x}$) = x).

The weighted least-squares criterion, where the objective is to minimize the sum of the squares of the weighted deviations of the estimated measurements, $\hat{z}$, from the actual measurements, z.

The minimum variance criterion, where the objective is to minimize the expected value of the sum of the squares of the deviations of the estimated components of the state variable vector from the corresponding components of the true state variable vector.

The maximum likelihood method introduces the measurement error weighting matrix [R] in a straightforward manner.

$$X^{est} = [[H]^{T}\ [R^{-1}]\ [H]]^{-1}.\ [H]^{T}\ [R^{-1}]\ Z^{meas} \qquad (3.2.1)$$

Where

X^{est}: is a vector represents the estimated values for the phase angles.

[H]: an N m by Ns matrix containing the coefficients of the linear function fi (x).

Z^{meas} : is a vector represents the measured values from the transducers.

N m: number of measurements.

N_s: number of unknown parameters being estimated.

$$Z^{meas} = \begin{pmatrix} Z_1^{meas} \\ Z_2^{meas} \\ . \\ . \\ Z_{N\,m}^{meas} \end{pmatrix}$$

[R] is called the covariance matrix of measurement errors, and equal to: -

$$R = \begin{pmatrix} \sigma_1^2 & & & & \\ & \sigma_2^2 & & & \\ & & . & & \\ & & & . & \\ & & & & \sigma_{Nm}^2 \end{pmatrix}$$

3.3 ESTIMATION OF QUANTITIES NOT BEING MEASURED

The other useful feature of a state estimator calculation is the ability to calculate (or estimate) quantities not being measured. This is most useful in cases of failure of communication channels connecting operation centers to remote data-gathering equipment or when the remote data-gathering equipment fails. Often data from some network substations are simply unavailable because no transducers or data gathering equipment were ever installed.

CHAPTER FOUR

SYSTEM DESCRIPTION AND MODELING

4 SYSTEM DESCRIPTION AND MODELING

4.1 System description

The National Grid system consists of 78 bus bars. The generating units are distributed on 15 bus including Rosaries 7 generating units at one reference bus and the load is distributed on 35 buses.

It also consists of 101 transmission lines including 24 two-winding transformers on 24 lines & 19 three-winding transformers on 54 lines.

4.2 Three-Winding Transformer Reactance Modeling

The three-winding transformer reactances were obtained from the equations below (refer to equivalent circuit in fig (4.1)):

$$X_p = 0.5(X_{ps} + X_{pt} - X_{st}) \quad (4.1).$$

$$X_s = 0.5(X_{ps} + X_{st} - X_{pt}) \quad (4.2).$$

$$X_t = 0.5(X_{pt} + X_{st} - X_{ps}) \quad (4.3).$$

Where:

X_p: the Primary reactance.

X_s: the Secondary reactance.

X_t: the Tertiary reactance.

X_{ps}: the short circuit reactance between Primary and Secondary.

X_{st}: the short circuit reactance between Secondary and Tertiary.

X_{pt}: the short circuit reactance between Primary and Tertiary.

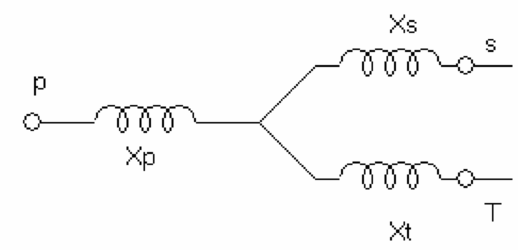


Fig (4.1)

Three-Winding Transformer

Equivalent Circuit

Star-delta transformation is employed to give equivalent delta reactance:

$$X_{ps} = (X_p X_s + X_p X_t + X_s X_t) / X_t \qquad (4.4)$$

$$X_{pt} = (X_p X_s + X_p X_t + X_s X_t) / X_s \qquad (4.5)$$

$$X_{st} = (X_p X_s + X_p X_t + X_s X_t) / X_p \qquad (4.6)$$

<u>4.3 Transmission Line Modeling</u>

A line is represented by its inductive reactance X, line resistance R is neglected and line charging admittance Y is neglected, as they have minimal impact on the power flow p.u through the line which is approximated as $(\theta_1-\theta_2)/ X$.

CHAPTER FIVE

APPLICATION AND RESULTS

5 APPLICATION AND RESULTS

The National Grid system is used as a model to calculate the Mw flow on its transmission lines (Base case), the effects of change when Khartoum north steam turbine units are shifted by (-10) Mw,and the effects when there is line outage as (SRJ110-SRPS110) line. A state estimator was then set-up to correlate these readings using dc flow methods in conjunction with a weighted-least- square estimator.

The analysis is done by means of computer programming using MATLAB, which is a high-performance language for technical computing. The results have been checked and compared using load flow simulation (Newton Raphson).

5.1 Application of State Estimator To NG

The NG system as shown in Fig (4.3) consists of 101 lines, and the measured lines are 78 which are distributed between the whole system buses. The flows on the other 23 Non measured lines are obtained by means of estimation techniques. The estimation formulae are three, depending on the number of parameters being estimated (Ns), and the number of measurements being made (Nm), according to reference[1] the formulae are as follows:

(I) when Ns < Nm (over determined case):

$$X^{est} = [[H]^{T} [R^{-1}] [H]]^{-1}. [H]^{T} [R^{-1}] Z^{meas} \quad (5\text{-}1)$$

(II) when Ns = Nm (completely determined case):

$$X^{est} = [H]^{-1} Z^{meas} \quad (5\text{-}2)$$

(III) when Ns > Nm (under determined case):

$$X^{est}=[H]^{T} [[H] [H]^{T}]^{-1} Z^{meas} \quad (5\text{-}3)$$

As shown above, with 78 lines (Nm) distributed between 78 busbars including the slack bus (1), (Ns) =77 busbars, so that the first formula should be applied. The [H] matrix in thiscase has an order of (78,77). The measured value (Z^{meas}) is taken from the load flow simulation.

(5.1.1) THE MEASURED LINES

They consist of the Radial lines and many other lines distributed between the whole system buses as shown in the table below.

Table 5.1 NG Measured Lines

Line Number	Starting Bus	Ending Bus	Real Flow
1	1	2	105.2
2	2	3	105.2
3	3	19	66.9
4	19	44	4.5
5	6	7	17.5
6	6	11	9.2
7	11	14	13.2
8	17	22	6.3
9	22	31	17.5
10	31	32	17.5
11	34	38	-5.8
12	38	43	-18.9
13	43	49	52.8
14	52	55	-8.6
15	58	13	-83.9
16	47	69	-0.9
17	59	66	-9
18	59	69	16.9
19	55	13	-52.4
20	7	10	6.8
21	11	12	-11.7
22	22	27	6.8
23	22	28	6.6
24	31	33	0
25	34	35	6.6
26	47	45	-10
27	47	46	5.2
28	59	60	-9
29	59	61	-13
30	69	62	-18
31	69	63	-15
32	69	64	-9
33	69	65	-9
34	66	67	-15
35	66	68	-15
36	13	66	9.7

37	13	70	-28
38	13	71	-28
39	13	18	-45
40	13	76	-45
41	69	77	12.1
42	69	78	2.3
43	6	4	11.5
44	6	5	-1.3
45	8	9	-1.2
46	16	15	10.6
47	22	20	0
48	22	21	0
49	23	24	-2.7
50	25	26	7
51	29	30	4.3
52	37	36	5.3
53	39	40	8.1
54	43	41	0
55	43	42	0
56	47	48	0
57	72	73	0
58	74	75	0.7
59	3	5	1.3
60	22	24	2.7
61	49	51	12.8
62	52	54	7.9
63	55	57	14.1
64	3	6	36.9
65	7	8	4.3
66	14	16	13.1
67	19	22	62.4
68	22	25	12.5
69	22	29	6.5
70	34	37	15.3
71	38	39	8.2
72	44	43	4.5
73	43	47	3.1
74	49	50	26.7
75	52	53	14
76	55	56	29.7
77	34	72	0
78	17	74	1.4

(5.1.2) THE NON-MEASURED LINES

It has been found that in order to produce accurate results, for every non measured line there should exist at least one loop which contains only that line as unmeasured. Table (5-2) shows the non-measured lines.

Line Number	Starting Bus	Ending Bus	REAL FLOW
1	11	17	7.7
2	22	34	16.2
3	49	52	13.3
4	43	58	-70.3
5	58	59	13.6
6	50	51	-1.7
7	53	54	2.7
8	56	57	-2.3
9	3	4	0
10	7	9	6.4
11	14	15	0
12	19	20	0
13	19	21	0
14	22	26	0
15	22	30	0
16	34	36	0
17	38	40	0
18	44	41	0
19	44	42	0
20	43	48	0
21	34	73	0
22	17	75	0
23	22	23	0

Table (5.2)

NG Non-Measured Lines

5.2 Excel Data File

The data is prepared in EXCEL file and imported to MAT LAB by means of EXCEL link function called (xlsread). The EXCEL file is shown in figure (5.1) below.

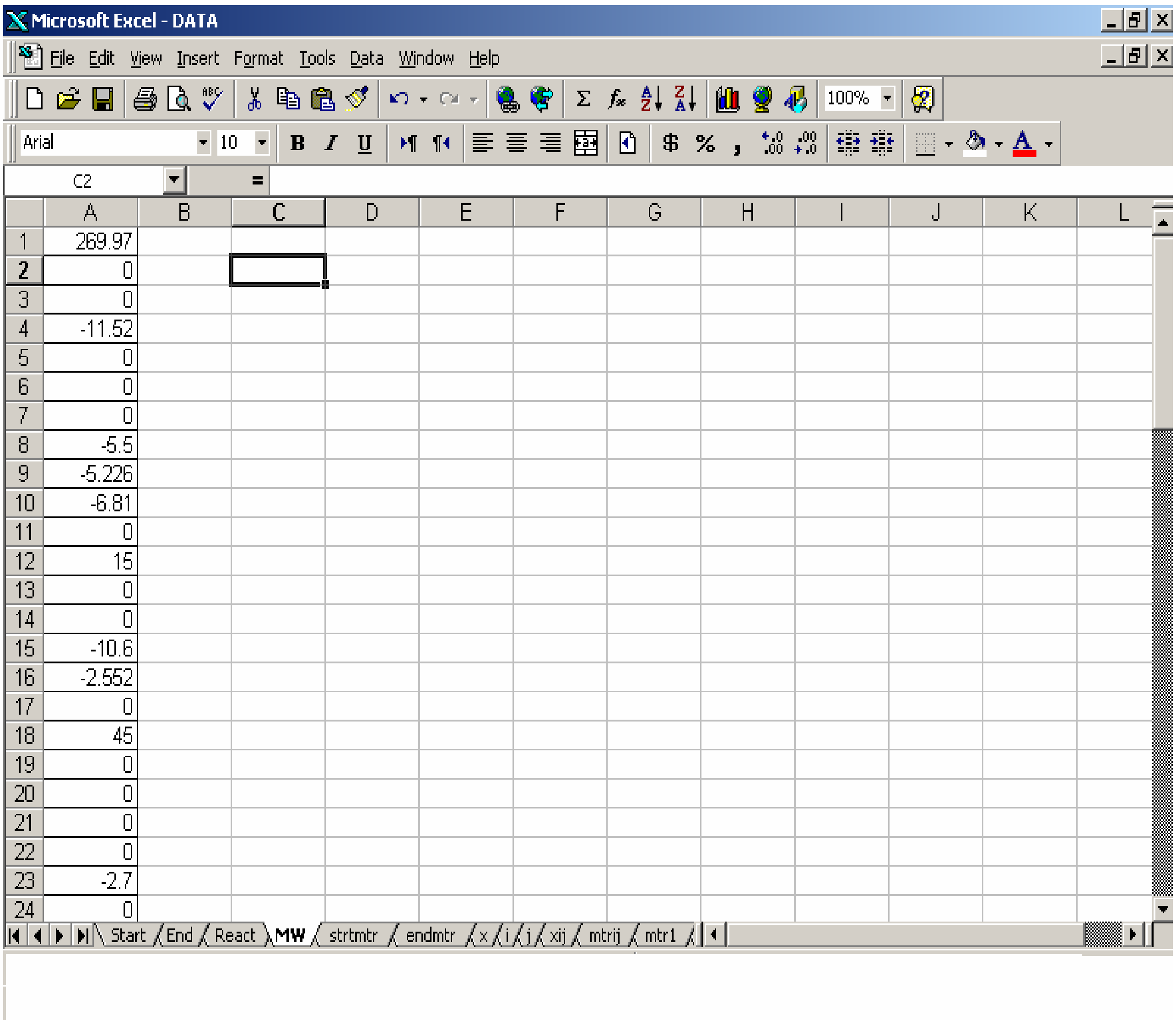
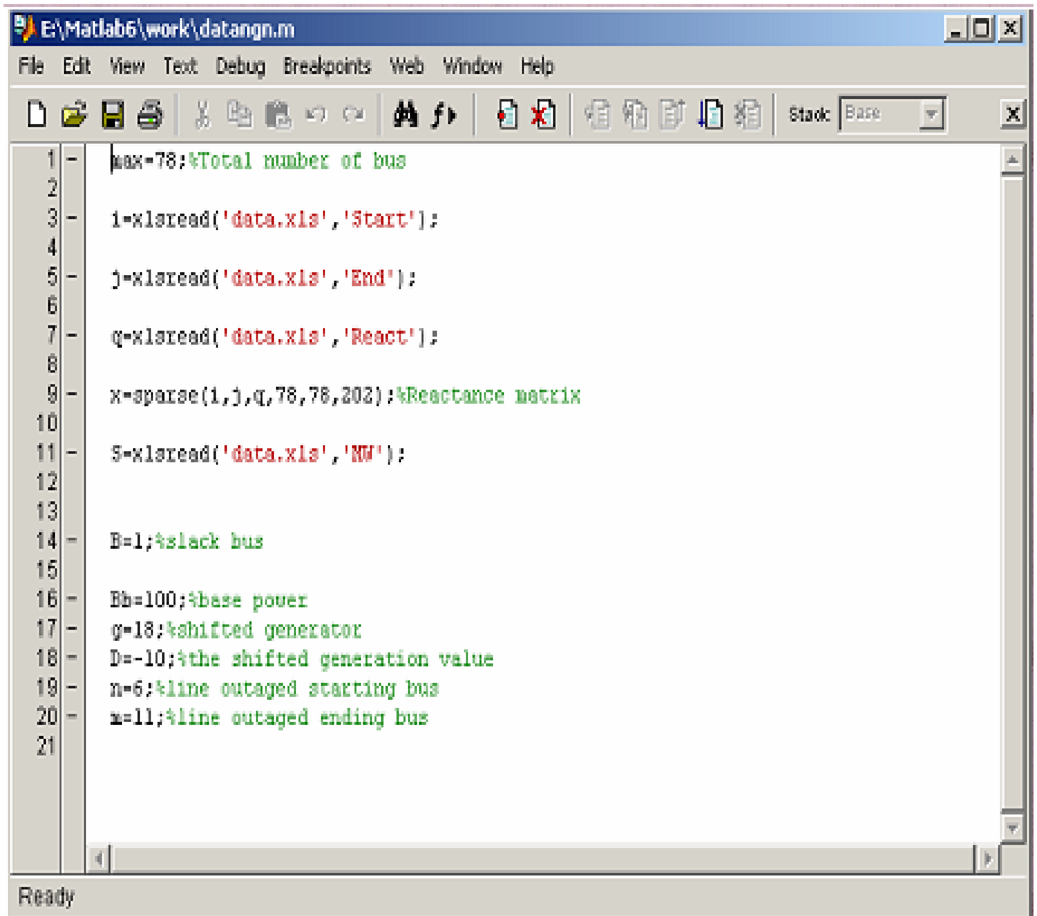


Figure (5.1)

data.xls file

5.3 MATLAB Data File (datangn.m)

This file is of type (*.m), (MATLAB script file) and some data is exported from EXCEL (data.xls).



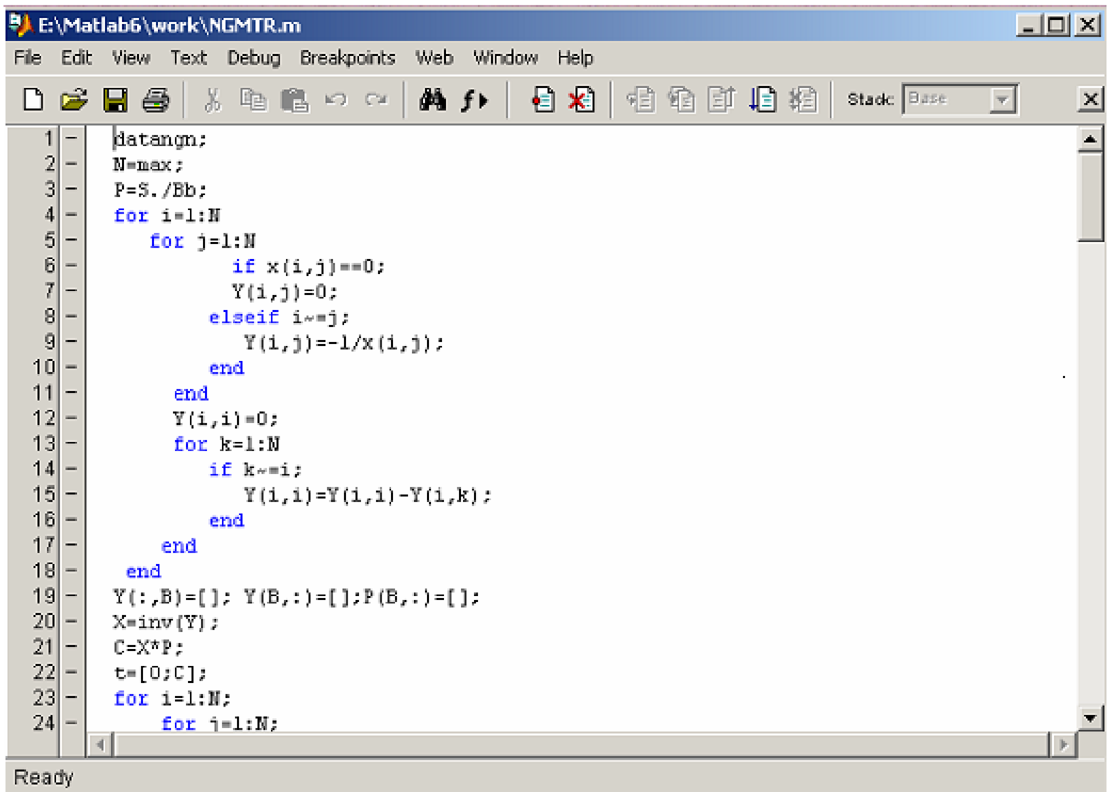

```
max=78;%Total number of bus

i=xlsread('data.xls','Start');

j=xlsread('data.xls','End');

q=xlsread('data.xls','React');

x=sparse(i,j,q,78,78,202);%Reactance matrix

S=xlsread('data.xls','MW');


B=1;%slack bus

Bb=100;%base power
g=18;%shifted generator
D=-10;%the shifted generation value
n=6;%line outaged starting bus
m=11;%line outaged ending bus
```

Figure (5.2)

Datangn.m file

5.4 Program File (NGMTR.m)

State estimator program file




```
datangn;
N=max;
P=S./Bb;
for i=1:N
   for j=1:N
          if x(i,j)==0;
          Y(i,j)=0;
        elseif i~=j;
           Y(i,j)=-1/x(i,j);
        end
     end
     Y(i,i)=0;
     for k=1:N
        if k~=i;
           Y(i,i)=Y(i,i)-Y(i,k);
        end
    end
 end
Y(:,B)=[]; Y(B,:)=[];P(B,:)=[];
X=inv(Y);
C=X*P;
t=[0;C];
for i=1:N;
    for j=1:N;
```

Figure (5.3)

State estimator program file

5.5 MATLAB Command Window

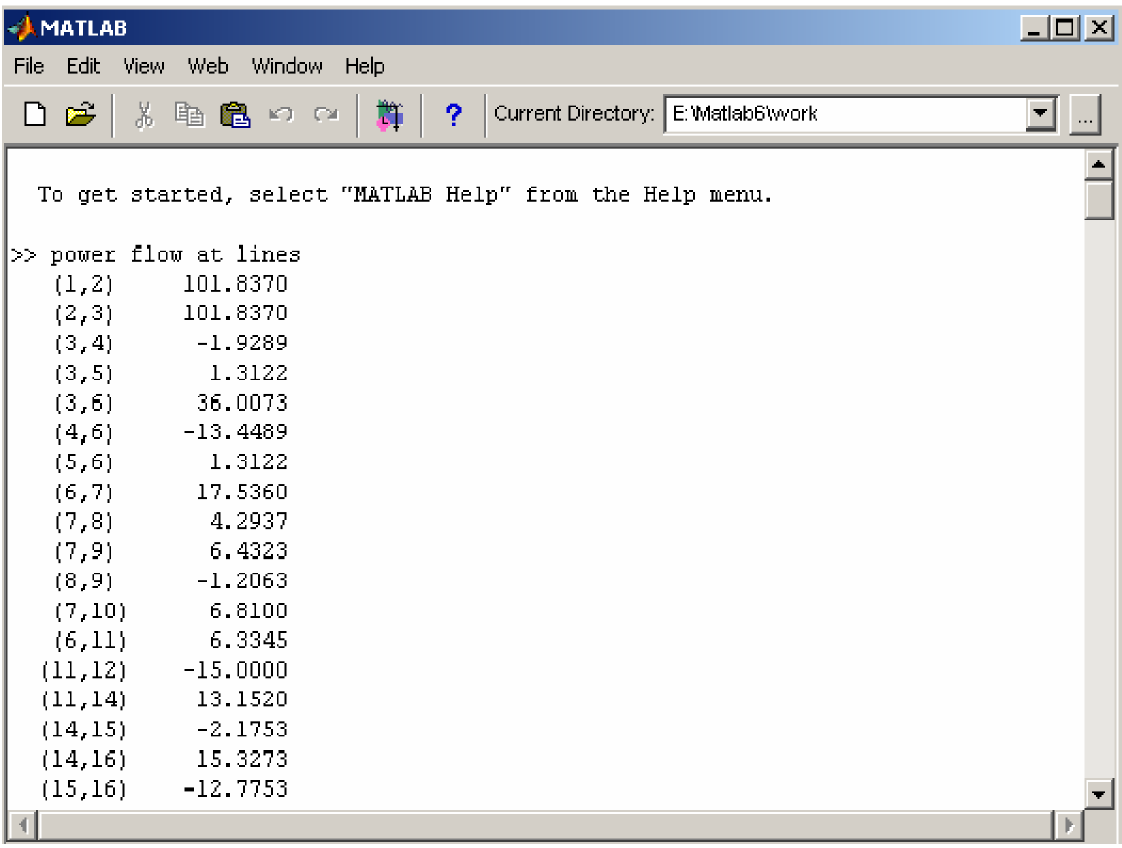


Figure (5.4)

State estimator results using MATLAB command window

5.6 RESULTS

5.6.1 MW flow on NG lines (base case)

Power flow at lines

(1,2)	101.8370
(2,3)	101.8370
(3,4)	-1.9289
(3,5)	1.3122
(3,6)	36.0073
(4,6)	-13.4489
(5,6)	1.3122
(6,7)	17.5360
(7,8)	4.2937
(7,9)	6.4323
(8,9)	-1.2063
(7,10)	6.8100
(6,11)	6.3345
(11,12)	-15.0000
(11,14)	13.1520
(14,15)	-2.1753
(14,16)	15.3273
(15,16)	-12.7753
(11,17)	8.1825
(13,18)	-45.0000
(3,19)	66.4465
(19,20)	-1.3814
(19,21)	-1.3814
(17,22)	6.7825

(19,22)	64.4534
(20,22)	-1.3814
(21,22)	-1.3814
(22,23)	-4.2655
(22,24)	6.9655
(23,24)	-6.9655
(22,25)	14.0844
(22,26)	-1.5844
(25,26)	8.5844
(22,27)	6.7710
(22,28)	6.6000
(22,29)	8.0892
(22,30)	-1.5892
(29,30)	5.8892
(22,31)	17.5340
(31,32)	17.5340
(31,33)	0.0000
(22,34)	15.8681
(34,35)	6.6000
(34,36)	-2.1105
(34,37)	17.4295
(36,37)	-7.4295
(34,38)	-6.0509
(38,39)	9.5956
(38,40)	-1.4436
(39,40)	9.5956
(38,43)	-19.2029
(41,43)	-0.1175
(42,43)	-0.1175

(19,44)	4.7559
(41,44)	0.1175
(42,44)	0.1175
(43,44)	-4.9910
(43,47)	3.5872
(45,47)	10.0000
(46,47)	-5.2000
(43,48)	-0.5750
(47,48)	0.5750
(43,49)	52.6790
(49,50)	26.6845
(49,51)	12.7705
(50,51)	-1.7155
(49,52)	13.2240
(52,53)	14.0138
(52,54)	7.9052
(53,54)	2.6948
(13,55)	52.5320
(52,55)	-8.6950
(55,56)	29.7360
(55,57)	14.1010
(56,57)	-2.3010
(13,58)	83.7791
(43,58)	-70.1382
(58,59)	13.6409
(59,60)	-9.0000
(59,61)	-13.0000
(13,66)	9.6889
(59,66)	-9.0019

(66,67)	-15.0000
(66,68)	-15.0000
(47,69)	-0.9558
(59,69)	16.9558
(62,69)	18.0000
(63,69)	15.0000
(64,69)	9.0000
(65,69)	9.0000
(13,70)	-28.0000
(13,71)	-28.0000
(34,72)	0.0000
(34,73)	-0.0000
(72,73)	0.0000
(17,74)	1.5855
(17,75)	-0.1855
(74,75)	0.8855
(13,76)	-45.0000
(69,77)	12.1000
(69,78)	2.3000

5.6.2 MW flow after a shift in (khrt North Steam. T) Output

Power flow after the generation shift

(1,2)	111.8370
(2,3)	111.8370
(3,4)	-1.9501
(3,5)	1.3430
(3,6)	36.8540
(4,6)	-13.4701
(5,6)	1.3430
(6,7)	17.5360
(7,8)	4.2937
(7,9)	6.4323
(8,9)	-1.2063
(7,10)	6.8100
(6,11)	7.1909
(11,12)	-15.0000
(11,14)	13.1520
(14,15)	-2.1753
(14,16)	15.3273
(15,16)	-12.7753
(11,17)	9.0389
(13,18)	-35.0000
(3,19)	75.5901
(19,20)	-1.3940
(19,21)	-1.3940
(17,22)	7.6389
(19,22)	65.0404
(20,22)	-1.3940
(21,22)	-1.3940
(22,23)	-4.2655
(22,24)	6.9655
(23,24)	-6.9655
(22,25)	14.0844
(22,26)	-1.5844
(25,26)	8.5844
(22,27)	6.7710
(22,28)	6.6000
(22,29)	8.0892
(22,30)	-1.5892
(29,30)	5.8892

(22,31)	17.5340
(31,32)	17.5340
(31,33)	0.0000
(22,34)	17.2864
(34,35)	6.6000
(34,36)	-2.1105
(34,37)	17.4295
(36,37)	-7.4295
(34,38)	-4.6326
(38,39)	9.5956
(38,40)	-1.4436
(39,40)	9.5956
(38,43)	-17.7846
(41,43)	-0.3297
(42,43)	-0.3297
(19,44)	13.3376
(41,44)	0.3297
(42,44)	0.3297
(43,44)	-13.9969
(43,47)	3.9579
(45,47)	10.0000
(46,47)	-5.2000
(43,48)	-0.6344
(47,48)	0.6344
(43,49)	54.3202
(49,50)	26.6845
(49,51)	12.7705
(50,51)	-1.7155
(49,52)	14.8652
(52,53)	14.0138
(52,54)	7.9052
(53,54)	2.6948
(13,55)	50.8908
(52,55)	-7.0538
(55,56)	29.7360
(55,57)	14.1010
(56,57)	-2.3010
(13,58)	75.6702
(43,58)	-62.0907
(58,59)	13.5796

(59,60)	-9.0000
(59,61)	-13.0000
(13,66)	9.4390
(59,66)	-8.7520
(66,67)	-15.0000
(66,68)	-15.0000
(47,69)	-0.6445
(59,69)	16.6445
(62,69)	18.0000
(63,69)	15.0000
(64,69)	9.0000
(65,69)	9.0000
(13,70)	-28.0000
(13,71)	-28.0000
(34,72)	0.0000
(34,73)	-0.0000
(72,73)	0.0000
(17,74)	1.5855
(17,75)	-0.1855
(74,75)	0.8855
(13,76)	-45.0000
(69,77)	12.1000
(69,78)	2.3000

5.6.3 MW flow after an outage of line (srj110-srps110)

Power flow after an outage of line

(1,2)	101.8370
(2,3)	101.8370
(3,4)	-1.7719
(3,5)	1.0839
(3,6)	29.7440
(4,6)	-13.2919
(5,6)	1.0839
(6,7)	17.5360
(7,8)	4.2937
(7,9)	6.4323
(8,9)	-1.2063
(7,10)	6.8100
(11,12)	-15.0000
(11,14)	13.1520
(14,15)	-2.1753
(14,16)	15.3273
(15,16)	-12.7753
(11,17)	1.8480
(13,18)	-45.0000
(3,19)	72.7810
(19,20)	-1.5176
(19,21)	-1.5176
(17,22)	0.4480
(19,22)	70.8094
(20,22)	-1.5176
(21,22)	-1.5176
(22,23)	-4.2655
(22,24)	6.9655
(23,24)	-6.9655
(22,25)	14.0844
(22,26)	-1.5844
(25,26)	8.5844
(22,27)	6.7710
(22,28)	6.6000
(22,29)	8.0892
(22,30)	-1.5892
(29,30)	5.8892

(22,31)	17.5340
(31,32)	17.5340
(31,33)	0.0000
(22,34)	15.6172
(34,35)	6.6000
(34,36)	-2.1105
(34,37)	17.4295
(36,37)	-7.4295
(34,38)	-6.3018
(38,39)	9.5956
(38,40)	-1.4436
(39,40)	9.5956
(38,43)	-19.4538
(41,43)	-0.1237
(42,43)	-0.1237
(19,44)	5.0068
(41,44)	0.1237
(42,44)	0.1237
(43,44)	-5.2543
(43,47)	3.5872
(45,47)	10.0000
(46,47)	-5.2000
(43,48)	-0.5750
(47,48)	0.5750
(43,49)	52.6790
(49,50)	26.6845
(49,51)	12.7705
(50,51)	-1.7155
(49,52)	13.2240
(52,53)	14.0138
(52,54)	7.9052
(53,54)	2.6948
(13,55)	52.5320
(52,55)	-8.6950
(55,56)	29.7360
(55,57)	14.1010
(56,57)	-2.3010
(13,58)	83.7791
(43,58)	-70.1382
(58,59)	13.6409

(59,60)	-9.0000
(59,61)	-13.0000
(13,66)	9.6889
(59,66)	-9.0019
(66,67)	-15.0000
(66,68)	-15.0000
(47,69)	-0.9558
(59,69)	16.9558
(62,69)	18.0000
(63,69)	15.0000
(64,69)	9.0000
(65,69)	9.0000
(13,70)	-28.0000
(13,71)	-28.0000
(34,72)	0.0000
(34,73)	-0.0000
(72,73)	0.0000
(17,74)	1.5855
(17,75)	-0.1855
(74,75)	0.8855
(13,76)	-45.0000
(69,77)	12.1000
(69,78)	2.3000

5.6.4 STATE ESTIMATOR RESULT

(Base case)

state estimator Result

(1,2)	105.2000
(2,3)	105.2000
(3,4)	-1.7903
(6,4)	11.5000
(3,5)	1.3519
(6,5)	-1.3115
(3,6)	36.8977
(6,7)	17.5000
(7,8)	4.3000
(7,9)	6.4436
(8,9)	-1.2000
(7,10)	6.8000
(6,11)	9.2000
(11,12)	-11.7000
(55,13)	-52.4000
(58,13)	-83.9000
(11,14)	13.2000
(14,15)	-1.8429
(16,15)	10.6000
(14,16)	13.1000
(11,17)	7.6180
(13,18)	-45.0000
(3,19)	66.9000
(19,20)	-1.2559
(19,21)	-1.2559
(17,22)	6.3000
(19,22)	62.4000
(22,23)	-1.6534
(22,24)	2.7000
(23,24)	-2.7000
(22,25)	12.5000
(22,26)	-1.3755
(25,26)	7.0000
(22,27)	6.8000
(22,28)	6.6000
(22,29)	6.5000
(22,30)	-1.2433
(29,30)	4.3000
(22,31)	17.5000
(31,32)	17.5000
(22,34)	15.4142
(34,35)	6.6000
(34,36)	-1.7901
(37,36)	5.3000
(34,37)	15.3000
(34,38)	-5.8000
(38,39)	8.2000
(38,40)	-1.2285
(39,40)	8.1000
(44,41)	-0.0986

(44,42)	-0.0986
(38,43)	-18.9000
(44,43)	4.5000
(19,44)	4.5000
(47,45)	-10.0000
(47,46)	5.2000
(43,47)	3.1000
(43,48)	-0.4564
(43,49)	52.8000
(49,50)	26.7000
(49,51)	12.8000
(50,51)	-1.6500
(49,52)	12.1694
(52,53)	14.0000
(52,54)	7.9000
(53,54)	2.7000
(52,55)	-8.6000
(55,56)	29.7000
(55,57)	14.1000
(56,57)	-2.2500
(43,58)	-70.6181
(58,59)	13.6439
(59,60)	-9.0000
(59,61)	-13.0000
(69,62)	-18.0000
(69,63)	-15.0000
(69,64)	-9.0000
(69,65)	-9.0000
(13,66)	9.7000
(59,66)	-9.0000
(66,67)	-15.0000
(66,68)	-15.0000
(47,69)	-0.9000
(59,69)	16.9000
(13,70)	-28.0000
(13,71)	-28.0000
(17,74)	1.4000
(17,75)	-0.1600
(74,75)	0.7000
(13,76)	-45.0000
(69,77)	12.1000
(69,78)	2.3000

5.6.5 Estimation after a shift in (khrt North Steam. T) Out put

state estimator Result

(1,2)	115.2000
(2,3)	115.2000
(3,4)	-1.8088
(6,4)	11.5000
(3,5)	1.3696
(6,5)	-1.3933
(3,6)	37.7014
(6,7)	17.5000
(7,8)	4.3000
(7,9)	6.4436
(8,9)	-1.2000
(7,10)	6.8000
(6,11)	10.0000
(11,12)	-11.7000
(55,13)	-50.8000
(58,13)	-75.8000
(11,14)	13.1000
(14,15)	-1.8528
(16,15)	10.6000
(14,16)	13.2000
(11,17)	8.4780
(13,18)	-35.0000
(3,19)	76.1000
(19,20)	-1.2680
(19,21)	-1.2680
(17,22)	7.2000
(19,22)	63.0000
(22,23)	-1.6534
(22,24)	2.7000
(23,24)	-2.7000
(22,25)	12.5000
(22,26)	-1.3755
(25,26)	7.0000
(22,27)	6.8000
(22,28)	6.6000
(22,29)	6.5000
(22,30)	-1.2433
(29,30)	4.3000
(22,31)	17.5000
(31,32)	17.5000
(22,34)	16.8179
(34,35)	6.6000
(34,36)	-1.7901
(37,36)	5.3000
(34,37)	15.3000
(34,38)	-4.4000
(38,39)	8.2000
(38,40)	-1.2336
(39,40)	8.2000
(44,41)	-0.2871
(44,42)	-0.2871

(38,43)	-17.5000
(44,43)	13.1000
(19,44)	13.1000
(47,45)	-10.0000
(47,46)	5.2000
(43,47)	3.4000
(43,48)	-0.5005
(47,48)	-0.0000
(43,49)	54.4000
(49,50)	26.7000
(49,51)	12.8000
(50,51)	-1.6500
(49,52)	13.9194
(52,53)	14.0000
(52,54)	7.9000
(53,54)	2.7000
(52,55)	-7.0000
(55,56)	29.7000
(55,57)	14.1000
(56,57)	-2.2500
(43,58)	-62.6563
(58,59)	13.4861
(59,60)	-9.0000
(59,61)	-13.0000
(69,62)	-18.0000
(69,63)	-15.0000
(69,64)	-9.0000
(69,65)	-9.0000
(13,66)	9.4000
(59,66)	-8.7000
(66,67)	-15.0000
(66,68)	-15.0000
(47,69)	-0.6000
(59,69)	16.6000
(13,70)	-28.0000
(13,71)	-28.0000
(34,72)	0.0000
(34,73)	-0.0000
(17,74)	1.4000
(17,75)	-0.1600
(74,75)	0.7000
(13,76)	-45.0000
(69,77)	12.1000
(69,78)	2.3000

5.6.6 Estimation after an outage of line (srj110-srps110)

state estimator Result

(1,2)	105.1000
(2,3)	105.1000
(3,4)	-1.5854
(6,4)	11.5000
(3,5)	1.0237
(6,5)	-1.0052
(3,6)	27.9989
(6,7)	17.5000
(7,8)	4.3000
(7,9)	6.4436
(8,9)	-1.2000
(7,10)	6.8000
(11,12)	-11.7000
(55,13)	-52.4000
(58,13)	-83.9000
(11,14)	13.2000
(14,15)	-1.8528
(16,15)	10.6000
(14,16)	13.2000
(11,17)	-1.4000
(13,18)	-45.0000
(3,19)	76.1000
(19,20)	-1.4331
(19,21)	-1.4331
(17,22)	-2.9000
(19,22)	71.2000
(22,23)	-1.6534
(22,24)	2.7000
(23,24)	-2.7000
(22,25)	12.5000
(22,26)	-1.3755
(25,26)	7.0000
(22,27)	6.8000
(22,28)	6.6000
(22,29)	6.5000
(22,30)	-1.2433
(29,30)	4.3000
(22,31)	17.5000
(31,32)	17.5000
(22,34)	15.0086
(34,35)	6.6000
(34,36)	-1.7901
(37,36)	5.3000
(34,37)	15.3000
(34,38)	-6.1000
(38,39)	8.2000
(38,40)	-1.2285
(39,40)	8.1000
(44,41)	-0.1052
(44,42)	-0.1052
(38,43)	-19.3000
(44,43)	4.8000
(19,44)	4.8000

(47,45)	-10.0000
(47,46)	5.2000
(43,47)	3.1000
(43,48)	-0.4564
(47,48)	-0.0000
(43,49)	52.8000
(49,50)	26.7000
(49,51)	12.8000
(50,51)	-1.6500
(49,52)	12.1694
(52,53)	14.0000
(52,54)	7.9000
(53,54)	2.7000
(52,55)	-8.6000
(55,56)	29.7000
(55,57)	14.1000
(56,57)	-2.2500
(43,58)	-70.6181
(58,59)	13.6439
(59,60)	-9.0000
(59,61)	-13.0000
(69,62)	-18.0000
(69,63)	-15.0000
(69,64)	-9.0000
(69,65)	-9.0000
(13,66)	9.7000
(59,66)	-9.0000
(66,67)	-15.0000
(66,68)	-15.0000
(47,69)	-0.9000
(59,69)	16.9000
(13,70)	-28.0000
(13,71)	-28.0000
(17,74)	1.4000
(17,75)	-0.1600
(74,75)	0.7000
(13,76)	-45.0000
(69,77)	12.1000
(69,78)	2.3000

5.7 Comparison of Results

The tables below show the comparison between the results using load flow simulation (Newton Raphson) tables (A) set, and Dc load flow (MATLAB implementation) tables (B) set. Tables (C) set, (D) set and (E) set shows the real flow depending on the load flow simulation and the estimated values using state estimation techniques.

- Tables (A1)&(B1) show the flow on NG transmission lines.
- Tables (A2)&(B2) show the flow on NG transmission lines after a shift (-10MW) at (khrt North gas. T) Output.
- Tables (A3)&(B3) show the flow on NG transmission lines after an outage of line (srj110-srps110)
- Tables (C1), (C2) show the estimation for the base case.
- Tables (D1), (D2) show the estimation after a shift (-10MW) at
- (Khartoum North Steam. T) Output.
- Tables (E1), (E2) show the estimation after an outage of line (srj110-srps110).

(5.7.1) Flow on NG Transmission Lines (Base Case)

Table(A1)					Table(B1)	
Between bus	Sending End		Reciving End		power flow at lines	
	MW	MVAr	MW	MVAr		
1 - 2	105.2	55.7	-105.2	-51.0	(1,2)	101.8370
2 - 3	105.2	51.0	-105.2	-37.6	(2,3)	101.8370
6 - 5	-1.3	-0.2	1.3	0.2	(5,6)	1.3122
3 - 5	1.3	0.2	-1.3	-0.2	(3,5)	1.3122
3 - 6	36.9	5.8	-36.9	-5.1	(3,6)	36.0073
7 - 10	6.8	0.1	-6.8	0.0	(7,10)	6.8100
6 - 7	17.5	1.4	-17.5	-0.2	(6,7)	17.5360
8 - 9	-1.2	0.0	1.2	0.0	(8,9)	-1.2063
7 - 8	4.3	0.1	-4.3	0.0	(7,8)	4.2937
6 - 11	9.2	3.8	-9.2	-3.7	(6,11)	6.3345
11 - 12	-11.7	0.2	11.7	0.0	(11,12)	-15.0000
11 - 14	13.2	0.7	-13.2	-0.2	(11,14)	13.1520
16 - 15	10.6	0.1	-10.6	0.0	(15,16)	-12.7753
14 - 16	13.1	0.2	-13.1	-0.1	(14,16)	15.3273
7 - 9	6.4	0.1	-6.4	0.0	(7,9)	6.4323
3 - 19	66.9	31.6	-66.9	-29.3	(3,19)	66.4465
19 - 22	62.4	6.2	-62.4	-4.9	(19,22)	64.4534
22 - 20	0.0	0.0	0.0	0.0	(20,22)	-1.3814
22 - 21	0.0	0.0	0.0	0.0	(21,22)	-1.3814
22 - 24	2.7	0.0	-2.7	0.0	(22,24)	6.9652
23 - 24	-2.7	0.0	2.7	0.0	(23,24)	-6.9652
22 - 25	12.5	0.2	-12.5	0.0	(22,25)	14.0844
25 - 26	7.0	0.0	-7.0	0.0	(25,26)	8.5844
22 - 27	6.8	0.1	-6.8	0.0	(22,27)	6.7710
22 - 28	6.6	0.0	-6.6	0.0	(22,28)	6.6000
22 - 29	6.5	0.0	-6.5	0.0	(22,29)	8.0892
29 - 30	4.3	0.0	-4.3	0.0	(29,30)	5.8892
4 - 6	-11.5	0.0	11.5	0.2	(4,6)	-13.4489
17 - 22	6.3	2.7	-6.3	-2.6	(17,22)	6.7825
22 - 31	17.5	2.7	-17.5	-1.8	(22,31)	17.5340
31 - 32	17.5	1.8	-17.5	0.0	(31,32)	17.5340
34 - 35	6.6	0.0	-6.6	0.0	(34,35)	6.6000
34 - 37	15.3	0.3	-15.3	0.0	(34,37)	17.4295
22 - 34	16.2	4.5	-16.2	-3.8	(22,34)	15.8681
37 - 36	5.3	0.0	-5.3	0.0	(36,37)	-7.4295
38 - 39	8.2	0.1	-8.2	0.0	(38,39)	9.5956
39 - 40	8.1	0.0	-8.1	0.0	(39,40)	9.5956
34 - 38	-5.8	3.5	5.8	-3.4	(34,38)	-6.0509
43 - 41	0.0	0.0	0.0	0.0	(41,43)	-0.1175
43 - 42	0.0	0.0	0.0	0.0	(42,43)	-0.1175
44 - 43	4.5	22.7	-4.5	-22.5	(43,44)	-4.9910
38 - 43	-18.9	3.2	18.9	-2.6	(38,43)	-19.2029
47 - 45	-10.0	0.1	10.0	0.0	(45,47)	10.0000
19 - 44	4.5	23.2	-4.5	-22.7	(19,44)	4.7559
47 - 48	0.0	0.0	0.0	0.0	(47,48)	0.5750
43 - 47	3.1	0.9	-3.1	-0.9	(43,47)	3.5872
47 - 46	5.2	0.0	-5.2	0.0	(46,47)	-5.2000
49 - 52	13.3	5.4	-13.3	-5.4	(49,52)	13.2240
50 - 51	-1.7	0.0	1.7	0.0	(50,51)	-1.7155
53 - 54	2.7	0.0	-2.7	0.0	(53,54)	2.6948

49 - 51	12.8	1.2	-12.8	0.0	(49,51)	12.7705
52 - 54	7.9	0.4	-7.9	0.0	(52,54)	7.9052
49 - 50	26.7	2.4	-26.7	0.0	(49,50)	26.6845
43 - 49	52.8	9.8	-52.8	-9.0	(43,49)	52.6790
52 - 53	14.0	0.7	-14.0	0.0	(52,53)	14.0138
52 - 55	-8.6	4.2	8.6	-4.2	(52,55)	-8.6950
56 - 57	-2.3	0.0	2.3	0.0	(56,57)	-2.3010
55 - 57	14.1	1.4	-14.1	0.0	(55,57)	14.1010
55 - 56	29.7	3.0	-29.7	0.0	(55,56)	29.7360
43 - 58	-70.3	14.4	70.3	-13.0	(43,58)	-70.1382
58 - 59	13.6	1.1	-13.6	-0.9	(58,59)	13.6409
59 - 61	-13.0	0.2	13.0	0.0	(59,61)	-13.0000
11 - 17	7.7	2.9	-7.7	-2.7	(11,17)	8.1825
47 - 69	-0.9	0.7	0.9	-0.7	(47,69)	-0.9558
59 - 66	-9.0	0.2	9.0	-0.2	(59,66)	-9.0019
59 - 60	-9.0	0.1	9.0	0.0	(59,60)	-9.0000
59 - 69	16.9	0.3	-16.9	-0.3	(59,69)	16.9558
58 - 13	-83.9	11.9	83.9	-11.5	(13,58)	83.7791
55 - 13	-52.4	-0.2	52.4	2.4	(13,55)	52.5320
69 - 62	-18.0	0.4	18.0	0.0	(62,69)	18.0000
69 - 63	-15.0	0.3	15.0	0.0	(63,69)	15.0000
69 - 64	-9.0	0.1	9.0	0.0	(64,69)	9.0000
69 - 65	-9.0	0.1	9.0	0.0	(65,69)	9.0000
66 - 67	-15.0	0.3	15.0	0.0	(66,67)	-15.0000
66 - 68	-15.0	0.3	15.0	0.0	(66,68)	-15.0000
13 - 66	9.7	0.6	-9.7	-0.5	(13,66)	9.6889
13 - 71	-28.0	1.2	28.0	0.0	(13,71)	-28.0000
13 - 70	-28.0	1.2	28.0	0.0	(13,70)	-28.0000
13 - 18	-45.0	3.0	45.0	0.0	(13,18)	-45.0000
13 - 76	-45.0	3.0	45.0	0.0	(13,76)	-45.0000
69 - 77	12.1	0.0	-12.1	0.0	(69,77)	12.1000
69 - 78	2.3	0.0	-2.3	0.0	(69,78)	2.3000
72 - 73	0.0	0.0	0.0	0.0	(72,73)	0.0000
34 - 72	0.0	0.0	0.0	0.0	(34,72)	0.0000
74 - 75	0.7	0.0	-0.7	0.0	(74,75)	0.8855
17 - 74	1.4	0.0	-1.4	0.0	(17,74)	1.5855
					(3,4)	-1.9289
					(14,15)	-2.1753
					(19,20)	-1.3814
					(19,21)	-1.3814
					(22,23)	-4.2652
					(22,30)	-1.5892
					(22,26)	-1.5844
					(34,36)	-2.1105
					(38,40)	-1.4436
					(41,44)	0.1175
					(42,44)	0.1175
					(43,48)	-0.5750
					(34,73)	0.0000
					(17,75)	-0.1855

(5.7.2) MW Flow after A Shift in (Khrt North Steam. T) Output

Table (A2)					Table (B2)	
Between bus	Sending End		Reciving End		shift=minus 10	
	MW	MVAr	MW	MVAr		
1 - 2	115.2	54.1	-115.2	-49.0	(1,2)	111.8370
2 - 3	115.2	49.0	-115.2	-34.2	(2,3)	111.8370
6 - 5	-1.4	-0.2	1.4	0.2	(5,6)	1.3430
3 - 5	1.4	0.2	-1.4	-0.2	(3,5)	1.3430
3 - 6	37.7	5.4	-37.7	-4.8	(3,6)	36.8540
7 - 10	6.8	0.1	-6.8	0.0	(7,10)	6.8100
6 - 7	17.5	1.3	-17.5	-0.2	(6,7)	17.5360
8 - 9	-1.2	0.0	1.2	0.0	(8,9)	-1.2063
7 - 8	4.3	0.0	-4.3	0.0	(7,8)	4.2937
6 - 11	10.0	3.4	-10.0	-3.4	(6,11)	7.1909
11 - 12	-11.7	0.2	11.7	0.0	(11,12)	-15.0000
11 - 14	13.1	0.6	-13.1	-0.2	(11,14)	13.1520
16 - 15	10.6	0.1	-10.6	0.0	(15,16)	-12.7753
14 - 16	13.2	0.2	-13.2	-0.1	(14,16)	15.3273
7 - 9	6.4	0.1	-6.4	0.0	(7,9)	6.4323
3 - 19	76.1	28.6	-76.1	-26.0	(3,19)	75.5901
19 - 22	63.0	5.8	-63.0	-4.5	(19,22)	65.0404
22 - 20	0.0	0.0	0.0	0.0	(20,22)	-1.3940
22 - 21	0.0	0.0	0.0	0.0	(21,22)	-1.3940
22 - 24	2.7	0.0	-2.7	0.0	(22,24)	6.9652
23 - 24	-2.7	0.0	2.7	0.0	(23,24)	-6.9652
22 - 25	12.5	0.2	-12.5	0.0	(22,25)	14.0844
25 - 26	7.0	0.0	-7.0	0.0	(25,26)	8.5844
22 - 27	6.8	0.1	-6.8	0.0	(22,27)	6.7710
22 - 28	6.6	0.0	-6.6	0.0	(22,28)	6.6000
22 - 29	6.5	0.0	-6.5	0.0	(22,29)	8.0892
29 - 30	4.3	0.0	-4.3	0.0	(29,30)	5.8892
4 - 6	-11.5	0.0	11.5	0.2	(4,6)	-13.4701
17 - 22	7.2	2.4	-7.2	-2.3	(17,22)	7.6389
22 - 31	17.5	2.6	-17.5	-1.7	(22,31)	17.5340
31 - 32	17.5	1.7	-17.5	0.0	(31,32)	17.5340
34 - 35	6.6	0.0	-6.6	0.0	(34,35)	6.6000
34 - 37	15.3	0.3	-15.3	0.0	(34,37)	17.4295
22 - 34	17.5	4.0	-17.5	-3.3	(22,34)	17.2864
37 - 36	5.3	0.0	-5.3	0.0	(36,37)	-7.4295
38 - 39	8.2	0.1	-8.2	0.0	(38,39)	9.5956
39 - 40	8.2	0.0	-8.2	0.0	(39,40)	9.5956
34 - 38	-4.4	3.0	4.4	-2.9	(34,38)	-4.6326
43 - 41	0.0	0.0	0.0	0.0	(41,43)	-0.3297
43 - 42	0.0	0.0	0.0	0.0	(42,43)	-0.3297
44 - 43	13.1	19.8	-13.1	-19.6	(43,44)	-13.9969
38 - 43	-17.5	2.8	17.5	-2.3	(38,43)	-17.7846
47 - 45	-10.0	0.1	10.0	0.0	(45,47)	10.0000
19 - 44	13.1	20.3	-13.1	-19.8	(19,44)	13.3376
47 - 48	0.0	0.0	0.0	0.0	(47,48)	0.6344
43 - 47	3.4	0.8	-3.4	-0.8	(43,47)	3.9579
47 - 46	5.2	0.0	-5.2	0.0	(46,47)	-5.2000
49 - 52	15.0	4.8	-15.0	-4.7	(49,52)	14.8652
50 - 51	-1.7	0.0	1.7	0.0	(50,51)	-1.7155

53 - 54	2.7	0.0	-2.7	0.0	(53,54)	2.6948
49 - 51	12.8	1.1	-12.8	0.0	(49,51)	12.7705
52 - 54	7.9	0.4	-7.9	0.0	(52,54)	7.9052
49 - 50	26.7	2.3	-26.7	0.0	(49,50)	26.6845
43 - 49	54.4	9.0	-54.4	-8.1	(43,49)	54.3202
52 - 53	14.0	0.7	-14.0	0.0	(52,53)	14.0138
52 - 55	-7.0	3.7	7.0	-3.7	(52,55)	-7.0538
56 - 57	-2.3	0.0	2.3	0.0	(56,57)	-2.3010
55 - 57	14.1	1.3	-14.1	0.0	(55,57)	14.1010
55 - 56	29.7	2.8	-29.7	0.0	(55,56)	29.7360
43 - 58	-62.3	12.2	62.3	-11.1	(43,58)	-62.0907
58 - 59	13.5	1.0	-13.5	-0.8	(58,59)	13.5796
59 - 61	-13.0	0.2	13.0	0.0	(59,61)	-13.0000
11 - 17	8.6	2.6	-8.6	-2.4	(11,17)	9.0389
47 - 69	-0.6	0.6	0.6	-0.6	(47,69)	-0.6445
59 - 66	-8.7	0.2	8.7	-0.1	(59,66)	-8.7520
59 - 60	-9.0	0.1	9.0	0.0	(59,60)	-9.0000
59 - 69	16.6	0.3	-16.6	-0.3	(59,69)	16.6445
58 - 13	-75.8	10.1	75.8	-9.8	(13,58)	75.6702
55 - 13	-50.8	-0.5	50.8	2.4	(13,55)	50.8908
69 - 62	-18.0	0.4	18.0	0.0	(62,69)	18.0000
69 - 63	-15.0	0.2	15.0	0.0	(63,69)	15.0000
69 - 64	-9.0	0.1	9.0	0.0	(64,69)	9.0000
69 - 65	-9.0	0.1	9.0	0.0	(65,69)	9.0000
66 - 67	-15.0	0.3	15.0	0.0	(66,67)	-15.0000
66 - 68	-15.0	0.3	15.0	0.0	(66,68)	-15.0000
13 - 66	9.4	0.6	-9.4	-0.5	(13,66)	9.4390
13 - 71	-28.0	1.1	28.0	0.0	(13,70)	-28.0000
13 - 70	-28.0	1.1	28.0	0.0	(13,71)	-28.0000
13 - 18	-35.0	1.7	35.0	0.0	(13,18)	-35.0000
13 - 76	-45.0	2.8	45.0	0.0	(13,76)	-45.0000
69 - 77	12.1	0.0	-12.1	0.0	(69,77)	12.1000
69 - 78	2.3	0.0	-2.3	0.0	(69,78)	2.3000
72 - 73	0.0	0.0	0.0	0.0	(72,73)	0.0000
34 - 72	0.0	0.0	0.0	0.0	(34,72)	0.0000
74 - 75	0.7	0.0	-0.7	0.0	(74,75)	0.8855
17 - 74	1.4	0.0	-1.4	0.0	(17,74)	1.5855
					(3,4)	-1.9501
					(14,15)	-2.1753
					(19,20)	-1.3940
					(19,21)	-1.3940
					(22,23)	-4.2652
					(22,26)	-1.5844
					(22,30)	-1.5892
					(34,36)	-2.1105
					(38,40)	-1.4436
					(41,44)	0.3297
					(42,44)	0.3297
					(43,48)	-0.6344
					(34,73)	0.0000
					(17,75)	-0.1855
					(13,76)	-45.0000
					(69,77)	12.1000
					(69,78)	2.3000

(5.7.3) MW Flow after an Outage of Line (SRJ110-SRPS110)

Table (A3)					Table (B3)	
Between bus	Sending End		Reciving End			
	MW	MVAr	MW	MVAr		
1 - 2	105.1	53.0	-105.1	-48.6	(1,2)	101.8370
2 - 3	105.1	48.6	-105.1	-36.0	(2,3)	101.8370
6 - 5	-1.0	-0.1	1.0	0.1	(5,6)	1.0839
3 - 5	1.0	0.1	-1.0	-0.1	(3,5)	1.0839
3 - 6	28.0	1.8	-28.0	-1.4	(3,6)	29.7440
7 - 10	6.8	0.1	-6.8	0.0	(7,10)	6.8100
6 - 7	17.5	1.3	-17.5	-0.2	(6,7)	17.5360
8 - 9	-1.2	0.0	1.2	0.0	(8,9)	-1.2063
7 - 8	4.3	0.0	-4.3	0.0	(7,8)	4.2937
11 - 12	-11.7	0.2	11.7	0.0	(11,12)	-15.0000
11 - 14	13.2	0.7	-13.2	-0.2	(11,14)	13.1520
16 - 15	10.6	0.1	-10.6	0.0	(15,16)	-12.7753
14 - 16	13.1	0.2	-13.1	-0.1	(14,16)	15.3273
7 - 9	6.4	0.1	-6.4	0.0	(7,9)	6.4323
3 - 19	76.1	34.1	-76.1	-31.4	(3,19)	72.7810
19 - 22	71.3	9.4	-71.3	-7.8	(19,22)	70.8094
22 - 20	0.0	0.0	0.0	0.0	(20,22)	-1.5176
22 - 21	0.0	0.0	0.0	0.0	(21,22)	-1.5176
22 - 24	2.7	0.0	-2.7	0.0	(22,24)	6.9652
23 - 24	-2.7	0.0	2.7	0.0	(23,24)	-6.9652
22 - 25	12.5	0.2	-12.5	0.0	(22,25)	14.0844
25 - 26	7.0	0.0	-7.0	0.0	(25,26)	8.5844
22 - 27	6.8	0.1	-6.8	0.0	(22,27)	6.7710
22 - 28	6.6	0.0	-6.6	0.0	(22,28)	6.6000
22 - 29	6.5	0.0	-6.5	0.0	(22,29)	8.0892
29 - 30	4.3	0.0	-4.3	0.0	(29,30)	5.8892
4 - 6	-11.5	0.0	11.5	0.2	(4,6)	-13.2919
17 - 22	-2.8	-0.8	2.8	0.9	(17,22)	0.4480
22 - 31	17.5	2.6	-17.5	-1.7	(22,31)	17.5340
31 - 32	17.5	1.7	-17.5	0.0	(31,32)	17.5340
34 - 35	6.6	0.0	-6.6	0.0	(34,35)	6.6000
34 - 37	15.3	0.3	-15.3	0.0	(34,37)	17.4295
22 - 34	15.8	4.1	-15.8	-3.5	(22,34)	15.6172
37 - 36	5.3	0.0	-5.3	0.0	(36,37)	-7.4295
38 - 39	8.1	0.1	-8.1	0.0	(38,39)	9.5956
39 - 40	8.2	0.0	-8.2	0.0	(39,40)	9.5956
34 - 38	-6.1	3.2	6.1	-3.0	(34,38)	-6.3018
43 - 41	0.0	0.0	0.0	0.0	(41,43)	-0.1237
43 - 42	0.0	0.0	0.0	0.0	(42,43)	-0.1237
44 - 43	4.8	21.6	-4.8	-21.4	(43,44)	-5.2543
38 - 43	-19.3	2.9	19.3	-2.3	(38,43)	-19.4538
47 - 45	-10.0	0.1	10.0	0.0	(45,47)	10.0000
19 - 44	4.8	22.0	-4.8	-21.6	(19,44)	5.0068
47 - 48	0.0	0.0	0.0	0.0	(47,48)	0.5750
43 - 47	3.1	0.8	-3.1	-0.8	(43,47)	3.5872
47 - 46	5.2	0.0	-5.2	0.0	(46,47)	-5.2000
49 - 52	13.3	5.1	-13.3	-5.1	(49,52)	13.2240
50 - 51	-1.7	0.0	1.7	0.0	(50,51)	-1.7155

53 - 54	2.7	0.0	-2.7	0.0	(53,54)	2.6948
49 - 51	12.8	1.1	-12.8	0.0	(49,51)	12.7705
52 - 54	7.9	0.4	-7.9	0.0	(52,54)	7.9052
49 - 50	26.7	2.3	-26.7	0.0	(49,50)	26.6845
43 - 49	52.8	9.3	-52.8	-8.5	(43,49)	52.6790
52 - 53	14.0	0.7	-14.0	0.0	(52,53)	14.0138
52 - 55	-8.6	4.0	8.6	-4.0	(52,55)	-8.6950
56 - 57	-2.3	0.0	2.3	0.0	(56,57)	-2.3010
55 - 57	14.1	1.3	-14.1	0.0	(55,57)	14.1010
55 - 56	29.7	2.9	-29.7	0.0	(55,56)	29.7360
43 - 58	-70.3	13.6	70.3	-12.2	(43,58)	-70.1382
58 - 59	13.6	1.0	-13.6	-0.8	(58,59)	13.6409
59 - 61	-13.0	0.2	13.0	0.0	(59,61)	-13.0000
11 - 17	-1.4	-0.8	1.4	0.8	(11,17)	1.8480
47 - 69	-0.9	0.7	0.9	-0.7	(47,69)	-0.9558
59 - 66	-9.0	0.2	9.0	-0.1	(59,66)	-9.0019
59 - 60	-9.0	0.1	9.0	0.0	(59,60)	-9.0000
59 - 69	16.9	0.3	-16.9	-0.2	(59,69)	16.9558
58 - 13	-83.9	11.2	83.9	-10.8	(13,58)	83.7791
55 - 13	-52.4	-0.2	52.4	2.3	(13,55)	52.5320
69 - 62	-18.0	0.4	18.0	0.0	(62,69)	18.0000
69 - 63	-15.0	0.2	15.0	0.0	(63,69)	15.0000
69 - 64	-9.0	0.1	9.0	0.0	(64,69)	9.0000
69 - 65	-9.0	0.1	9.0	0.0	(65,69)	9.0000
66 - 67	-15.0	0.3	15.0	0.0	(66,67)	-15.0000
66 - 68	-15.0	0.3	15.0	0.0	(66,68)	-15.0000
13 - 66	9.7	0.6	-9.7	-0.5	(13,66)	9.6889
13 - 71	-28.0	1.1	28.0	0.0	(13,70)	-28.0000
13 - 70	-28.0	1.1	28.0	0.0	(13,71)	-28.0000
13 - 18	-45.0	2.8	45.0	0.0	(13,18)	-45.0000
13 - 76	-45.0	2.8	45.0	0.0	(13,76)	-45.0000
69 - 77	12.1	0.0	-12.1	0.0	(69,77)	12.1000
69 - 78	2.3	0.0	-2.3	0.0	(69,78)	2.3000
72 - 73	0.0	0.0	0.0	0.0	(72,73)	0.0000
34 - 72	0.0	0.0	0.0	0.0	(34,72)	0.0000
74 - 75	0.7	0.0	-0.7	0.0	(74,75)	0.8855
17 - 74	1.4	0.0	-1.4	0.0	(17,74)	1.5855
					(3,4)	-1.7719
					(14,15)	-2.1753
					(19,20)	-1.5176
					(19,21)	-1.5176
					(22,23)	-4.2652
					(22,26)	-1.5844
					(22,30)	-1.5892
					(34,36)	-2.1105
					(38,40)	-1.4436
					(41,44)	0.1237
					(42,44)	0.1237
					(43,48)	-0.5750
					(34,73)	0.0000
					(17,75)	-0.1855
					(69,78)	2.3000
					(13,76)	-45.0000
					(69,77)	12.1000
					(69,78)	2.3000

(5.7.4) THE BASE CASE ESTIMATION

(i) Measured Lines

Line No	START	END	real flow	estimator result
1	1	2	105.2	(1,2) 105.2000
2	2	3	105.2	(2,3) 105.2000
3	3	19	66.9	(3,19) 66.9000
4	19	44	4.5	(19,44) 4.5000
5	6	7	17.5	(6,7) 17.5000
6	6	11	9.2	(6,11) 9.2000
7	11	14	13.2	(11,14) 13.2000
8	17	22	6.3	(17,22) 6.3000
9	22	31	17.5	(22,31) 17.5000
10	31	32	17.5	(31,32) 17.5000
11	34	38	-5.8	(34,38) -5.8000
12	38	43	-18.9	(38,43) -18.9000
13	43	49	52.8	(43,49) 52.8000
14	52	55	-8.6	(52,55) -8.6000
15	58	13	-83.9	(58,13) -83.9000
16	47	69	-0.9	(47,69) -0.9000
17	59	66	-9	(59,66) -9.0000
18	59	69	16.9	(59,69) 16.9000
19	55	13	-52.4	(55,13) -52.4000
20	7	10	6.8	(7,10) 6.8000
21	11	12	-11.7	(11,12) -11.7000
22	22	27	6.8	(22,27) 6.8000
23	22	28	6.6	(22,28) 6.6000
24	31	33	0	(31,33) 0.0000
25	34	35	6.6	(34,35) 6.6000
26	47	45	-10	(47,45) -10.0000
27	47	46	5.2	(47,46) 5.2000
28	59	60	-9	(59,60) -9.0000
29	59	61	-13	(59,61) -13.0000
30	69	62	-18	(69,62) -18.0000
31	69	63	-15	(69,63) -15.0000
32	69	64	-9	(69,64) -9.0000
33	69	65	-9	(69,65) -9.0000
34	66	67	-15	(66,67) -15.0000
35	66	68	-15	(66,68) -15.0000
36	13	66	9.7	(13,66) 9.7000
37	13	70	-28	(13,70) -28.0000
38	13	71	-28	(13,71) -28.0000
39	13	18	-45	(13,18) -45.0000
40	13	76	-45	(13,76) -45.0000
41	69	77	12.1	(69,77) 12.1000
42	69	78	2.3	(69,78) 2.3000
43	6	4	11.5	(6,4) 11.5000

44	6	5	-1.3	(6,5) -1.3115
45	8	9	-1.2	(8,9) -1.2000
46	16	15	10.6	(16,15) 10.6000
47	22	20	0	(22,20) 0.0000
48	22	21	0	(22,21) 0.0000
49	23	24	-2.7	(23,24) -2.7000
50	25	26	7	(25,26) 7.0000
51	29	30	4.3	(29,30) 4.3000
52	37	36	5.3	(37,36) 5.3000
53	39	40	8.1	(39,40) 8.1000
54	43	41	0	(43,41) 0.0000
55	43	42	0	(43,42) 00000
56	47	48	0	(47,48) 0.0000
57	72	73	0	(72,73) 0.0000
58	74	75	0.7	(74,75) 0.7000
59	3	5	1.3	(3,5) 1.3519
60	22	24	2.7	(22,24) 2.7000
61	49	51	12.8	(49,51) 12.8000
62	52	54	7.9	(52,54) 7.9000
63	55	57	14.1	(55,57) 14.1000
64	3	6	36.9	(3,6) 36.8977
65	7	8	4.3	(7,8) 4.3000
66	14	16	13.1	(14,16) 13.1000
67	19	22	62.4	(19,22) 62.4000
68	22	25	12.5	(22,25) 12.5000
69	22	29	6.5	(22,29) 6.5000
70	34	37	15.3	(34,37) 15.3000
71	38	39	8.2	(38,39) 8.2000
72	44	43	4.5	(44,43) 4.5000
73	43	47	3.1	(43,47) 3.1000
74	49	50	26.7	(49,50) 26.7000
75	52	53	14	(52,53) 14.0000
76	55	56	29.7	(55,56) 29.7000
77	34	72	0	(34,72) 0.0000
78	17	74	1.4	(17,74) 1.4000

TABLE (C1)

MEASURED LINES

(ii) Non-Measured Lines

LINE NO	STRT	END	REAL FLOW	estimator result
1	11	17	7.7	(11,17) 7.6180
2	22	34	16.2	(22,34) 15.4142
3	49	52	13.3	(49,52) 12.1694
4	43	58	-70.3	(43,58) -70.6181
5	58	59	13.6	(58,59) 13.6439
6	50	51	-1.7	(50,51) -1.6500
7	53	54	2.7	(53,54) 2.7000
8	56	57	-2.3	(56,57) -2.2500
9	3	4	0	(3,4) -1.7903
10	7	9	6.4	(7,9) 6.4436
11	14	15	0	(14,15) -1.8429
12	19	20	0	(19,20) -1.2559
13	19	21	0	(19,21) -1.2559
14	22	26	0	(22,26) -1.3755
15	22	30	0	(22,30) -1.2433
16	34	36	0	(34,36) -1.7901
17	38	40	0	(38,40) -1.2285
18	44	41	0	(44,41) -0.0986
19	44	42	0	(44,42) -0.0986
20	43	48	0	(43,48) -0.4564
21	34	73	0	(34,73) -0.0000
22	17	75	0	(17,75) -0.1600
23	22	23	0	(22,23) -1.6534

TABLE (C2)

NON_MEASURED LINES

(5.7.5) Estimation after A Shift In (khrt North (Steam. T)) Out Put.

(i) Measured Lines

LINE NO	START	END	REAL FLOW	ESTIMATOR RESULT
1	1	2	115.2	(1,2) 115.2000
2	2	3	115.2	(2,3) 115.2000
3	3	19	76.1	(3,19) 76.1000
4	19	44	13.1	(19,44) 13.1000
5	6	7	17.5	(6,7) 17.5000
6	6	11	10	(6,11) 10.0000
7	11	14	13.1	(11,14) 13.1000
8	17	22	7.2	(17,22) 7.2000
9	22	31	17.5	(22,31) 17.5000
10	31	32	17.5	(31,32) 17.5000
11	34	38	-4.4	(34,38) -4.4000
12	38	43	-17.5	(38,43) -17.5000
13	43	49	54.4	(43,49) 54.4000
14	52	55	-7	(52,55) -7.0000
15	58	13	-75.8	(58,13) -75.8000
16	47	69	-0.6	(47,69) -0.6000
17	59	66	-8.7	(59,66) -8.7000
18	59	69	16.6	(59,69) 16.6000
19	55	13	-50.8	(55,13) -50.8000
20	7	10	6.8	(7,10) 6.8000
21	11	12	-11.7	(11,12) -11.7000
22	22	27	6.8	(22,27) 6.8000
23	22	28	6.6	(22,28) 6.6000
24	31	33	0	(31,33) 0.0000
25	34	35	6.6	(34,35) 6.6000
26	47	45	-10	(47,45) -10.0000
27	47	46	5.2	(47,46) 5.2000
28	59	60	-9	(59,60) -9.0000
29	59	61	-13	(59,61) -13.0000
30	69	62	-18	(69,62) -18.0000
31	69	63	-15	(69,63) -15.0000
32	69	64	-9	(69,64) -9.0000
33	69	65	-9	(69,65) -9.0000
34	66	67	-15	(66,67) -15.0000
35	66	68	-15	(66,68) -15.0000
36	13	66	9.4	(13,66) 9.4000
37	13	70	-28	(13,70) -28.0000
38	13	71	-28	(13,71) -28.0000
39	13	18	-35	(13,18) -35.0000
40	13	76	-45	(13,76) -45.0000
41	69	77	12.1	(69,77) 12.1000
42	69	78	2.3	(69,78) 2.3000
43	6	4	11.5	(6,4) 11.5000
44	6	5	-1.4	(6,5) -1.3933
45	8	9	-1.2	(8,9) -1.2000
46	16	15	10.6	(16,15) 10.6000

47	22	20	0	(22,20) 0.0000
48	22	21	0	(22,21) 0.0000
49	23	24	-2.7	(23,24) -2.7000
50	25	26	7	(25,26) 7.0000
51	29	30	4.3	(29,30) 4.3000
52	37	36	5.3	(37,36) 5.3000
53	39	40	8.2	(39,40) 8.2000
54	43	41	0	(43,41) 0.0000
55	43	42	0	(43,42) 00000
56	47	48	0	(47,48) -0.0000
57	72	73	0	(72,73) 0.0000
58	74	75	0.7	(74,75) 0.7000
59	3	5	1.4	(3,5) 1.3696
60	22	24	2.7	(22,24) 2.7000
61	49	51	12.8	(49,51) 12.8000
62	52	54	7.9	(52,54) 7.9000
63	55	57	14.1	(55,57) 14.1000
64	3	6	37.7	(3,6) 37.7014
65	7	8	4.3	(7,8) 4.3000
66	14	16	13.2	(14,16) 13.2000
67	19	22	63	(19,22) 63.0000
68	22	25	12.5	(22,25) 12.5000
69	22	29	6.5	(22,29) 6.5000
70	34	37	15.3	(34,37) 15.3000
71	38	39	8.2	(38,39) 8.2000
72	44	43	13.1	(44,43) 13.1000
73	43	47	3.4	(43,47) 3.4000
74	49	50	26.7	(49,50) 26.7000
75	52	53	14	(52,53) 14.0000
76	55	56	29.7	(55,56) 29.7000
77	34	72	0	(34,72) 0.0000
78	17	74	1.4	(17,74) 1.4000

TABLE (D1)

MEASURED LINES

(ii) Non-Measured Lines

Line No	STRT	END	real flow	estimator result
1	11	17	8.6	(11,17) 8.4780
2	22	34	17.5	(22,34) 16.8179
3	49	52	15	(49,52) 13.9194
4	43	58	-62.3	(43,58) -62.6563
5	58	59	13.5	(58,59) 13.4861
6	50	51	-1.7	(50,51) -1.6500
7	53	54	2.7	(53,54) 2.7000
8	56	57	-2.3	(56,57) -2.2500
9	3	4	0	(3,4) -1.8088
10	7	9	6.4	(7,9) 6.4436
11	14	15	0	(14,15) -1.8528
12	19	20	0	(19,20) -1.2680
13	19	21	0	(19,21) -1.2680
14	22	26	0	(22,26) -1.3755
15	22	30	0	(22,30) -1.2433
16	34	36	0	(34,36) -1.7901
17	38	40	0	(38,40) -1.2336
18	44	41	0	(44,41) -0.2871
19	44	42	0	(44,42) -0.2871
20	43	48	0	(43,48) -0.5005
21	34	73	0	(34,73) -0.0000
22	17	75	0	(17,75) -0.1600
23	22	23	0	(22,23) -1.6534

TABLE (D2)

NON_MEASURED LINES

(5.7.6) Estimation after an Outage of (srj110-srps110):

(i) Measured Lines

Line No	STRT	END	real flow	estimator result
1	1	2	105.1	(1,2) 105.1000
2	2	3	105.1	(2,3) 105.1000
3	3	19	76.1	(3,19) 76.1000
4	19	44	4.8	(19,44) 4.8000
5	6	7	17.5	(6,7) 17.5000
6	11	17	-1.4	(11,17) -1.4000
7	11	14	13.2	(11,14) 13.2000
8	17	22	-2.9	(17,22) -2.9000
9	22	31	17.5	(22,31) 17.5000
10	31	32	17.5	(31,32) 17.5000
11	34	38	-6.1	(34,38) -6.1000
12	38	43	-19.3	(38,43) -19.3000
13	43	49	52.8	(43,49) 52.8000
14	52	55	-8.6	(52,55) -8.6000
15	58	13	-83.9	(58,13) -83.9000
16	47	69	-0.9	(47,69) -0.9000
17	59	66	-9	(59,66) -9.0000
18	59	69	16.9	(59,69) 16.9000
19	55	13	-52.4	(55,13) -52.4000
20	7	10	6.8	(7,10) 6.8000
21	11	12	-11.7	(11,12) -11.7000
22	22	27	6.8	(22,27) 6.8000
23	22	28	6.6	(22,28) 6.6000
24	31	33	0	(31,33) 0.0000
25	34	35	6.6	(34,35) 6.6000
26	47	45	-10	(47,45) -10.0000
27	47	46	5.2	(47,46) 5.2000
28	59	60	-9	(59,60) -9.0000
29	59	61	-13	(59,61) -13.0000
30	69	62	-18	(69,62) -18.0000
31	69	63	-15	(69,63) -15.0000
32	69	64	-9	(69,64) -9.0000
33	69	65	-9	(69,65) -9.0000
34	66	67	-15	(66,67) -15.0000
35	66	68	-15	(66,68) -15.0000
36	13	66	9.7	(13,66) 9.7000
37	13	70	-28	(13,70) -28.0000
38	13	71	-28	(13,71) -28.0000
39	13	18	-45	(13,18) -45.0000
40	13	76	-45	(13,76) -45.0000
41	69	77	12.1	(69,77) 12.1000

42	69	78	2.3	(69,78) 2.3000
43	6	4	11.5	(6,4) 11.5000
44	6	5	-1	(6,5) -1.0052
45	8	9	-1.2	(8,9) -1.2000
46	16	15	10.6	(16,15) 10.6000
47	22	20	0	(22,20) 0.0000
48	22	21	0	(22,21) 0.0000
49	23	24	-2.7	(23,24) -2.7000
50	25	26	7	(25,26) 7.0000
51	29	30	4.3	(29,30) 4.3000
52	37	36	5.3	(37,36) 5.3000
53	39	40	8.1	(39,40) 8.1000
54	43	41	0	(43,41) 0.0000
55	43	42	0	(43,42) 00000
56	47	48	0	(47,48) -0.0000
57	72	73	0	(72,73) 0.0000
58	74	75	0.7	(74,75) 0.7000
59	3	5	1	(3,5) 1.0237
60	22	24	2.7	(22,24) 2.7000
61	49	51	12.8	(49,51) 12.8000
62	52	54	7.9	(52,54) 7.9000
63	55	57	14.1	(55,57) 14.1000
64	3	6	28	(3,6) 27.9989
65	7	8	4.3	(7,8) 4.3000
66	14	16	13.2	(14,16) 13.2000
67	19	22	71.2	(19,22) 71.2000
68	22	25	12.5	(22,25) 12.5000
69	22	29	6.5	(22,29) 6.5000
70	34	37	15.3	(34,37) 15.3000
71	38	39	8.2	(38,39) 8.2000
72	44	43	4.8	(44,43) 4.8000
73	43	47	3.1	(43,47) 3.1000
74	49	50	26.7	(49,50) 26.7000
75	52	53	14	(52,53) 14.0000
76	55	56	29.7	(55,56) 29.7000
77	34	72	0	(34,72) 0.0000
78	17	74	1.4	(17,74) 1.4000

TABLE (E1)

MEASURED LINES

(ii) Non-Measured Lines

Line No	STRT	END	real flow	estimator result
1	22	34	15.8	(22,34) 15.0086
2	49	52	13.3	(49,52) 12.1694
3	43	58	-70.3	(43,58) -70.6181
4	58	59	13.6	(58,59) 13.6439
5	50	51	-1.7	(50,51) -1.6500
6	53	54	2.7	(53,54) 2.7000
7	56	57	-2.3	(56,57) -2.2500
8	3	4	0	(3,4) -1.5854
9	7	9	6.4	(7,9) 6.4436
10	14	15	0	(14,15) -1.8528
11	19	20	0	(19,20) -1.4331
12	19	21	0	(19,21) -1.4331
13	22	26	0	(22,26) -1.3755
14	22	30	0	(22,30) -1.2433
15	34	36	0	(34,36) -1.7901
16	38	40	0	(38,40) -1.2285
17	44	41	0	(44,41) -0.1052
18	44	42	0	(44,42) -0.1052
19	43	48	0	(43,48) -0.4564
20	34	73	0	(34,73) -0.0000
21	17	75	0	(17,75) -0.1600
22	22	23	0	(22,23) -1.6534

TABLE (E2)

NON_MEASURED LINES

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6 CONCLUSIONS

6.1 CONCLUSIONS

The percentage of non-measured to measured lines is (23%) and the average percentage error in the results for the non-measured lines is (0.0072%).

According to results and the comparisons with the load flow simulation, it has been found that, in order to produce accurate results; the measured lines should be distributed between all system busbars. The radial lines should be measured, and for every non measured line there should exist at least one loop which contains only that line as unmeasured. Those conditions ensure enough data and so leads to accurate results.

6.2 RECOMMENDATIONS

I strongly recommend to keep searching for accurate results in case of failure to comply with one or more of the conditions above , i.e when it is not possible to ensure proper working of the meters at the radial lines, and in the case of the existance of more than non-measured line at any loop.

The state estimator is designed for MW flow (line resistance R and charging admittance Y neglected), I recommend to extend the design to include these parameters and estimate the MVAR flow as well.

APPENDIX (A)

SYSTEM DATA

Bus Notation

BUS No	BUS NAME	(kV) level
1	rosgu	11
2	ros220	220
3	srj220	220
4	srj11	11
5	srj33	33
6	srj110	110
7	rbk110	110
8	rbk3w11	11
9	rbk3w33	33
10	rbk2w11	11
11	srps110	110
12	srpsg1	11
13	kn110	110
14	mna110	110
15	mna11	11
16	mna33	33
17	hglla110	110
18	kngst3	11
19	mg220	220
20	mg11-a	11
21	mg11rx4	11
22	mg110	110
23	mg7.5-11	11
24	mg7.5-33	33
25	mg17.5-11	11
26	mg17.5-33	33
27	mg15-11	11
28	mg2w7.5-11	11
29	mg12.5-11	11
30	mg12.5-33	33
31	fao110	110
32	gdf110	110
33	fao11	11
34	hasa110	110
35	hasa2w-11	11
36	hasa11	11
37	hasa33	33

38	bagr110	110
39	bagr11	11
40	bagr33	33
41	kilx11rx4	11
42	kilx11rx6	11
43	kilx110	110
44	kilx220	220
45	kilgt	11
46	kilx11	11
47	kilx33	33
48	kilx3w-11	11
49	mgrs110	110
50	mgrs33	33
51	mgrs11	11
52	frst110	110
53	frst33	33
54	frst11	11
55	omd110	110
56	omd33	33
57	omd11	11
58	kuku110	110
59	kuku33	33
60	kukugt2	11
61	kukugt1	11
62	burold	11
63	burgst	11
64	burn1	11
65	burn2	11
66	kn33	33
67	kngt1	11
68	kngt2	11
69	bur33	33
70	kngst1	11
71	kngst2	11
72	hasa2-33	33
73	hasa2-11	11
74	hglla-33	33
75	hglla-11	11
76	kngst4	11
77	burtx3-11	11
78	burtx4-11	11

TRANSMISSION LINE REACTANCES

STRT BUS	END BUS	REACTANCE
1	2	0.033
2	3	0.095
3	19	0.0362
19	44	0.073
6	7	0.334
6	11	0.0348
11	14	0.2213
11	17	0.209
17	22	0.122
22	31	0.242
31	32	0.494
22	34	0.191
34	38	0.278
38	43	0.139
43	49	0.024
49	52	0.024
52	55	0.024
43	58	0.023
58	13	0.0048
47	69	0.474
59	66	0.0855
59	69	0.01
55	13	0.0645

TWO-WINDING TRANSFORMER REACTANCES

STRT BUS	END BUS	REACTANCE
7	10	0.10005
11	12	0.1118
22	27	0.10005
22	28	0.09225
31	33	0.10005
34	35	0.09225
47	45	0.07708
47	46	0.111
58	59	0.093
59	60	0.132
59	61	0.093
69	62	0.11165
69	63	0.09105
69	64	0.11165
69	65	0.11165
66	67	0.115
66	68	0.115
13	66	0.093
13	70	0.12288
13	71	0.12288
13	18	0.11925
13	76	0.11925
69	77	0.02525
69	78	0.02525

THREE-WINDING TRANSFORMER REACTANCES

PR Bus	SEC Bus	TER Bus	x(p,s)	x(p,t)	x(s,t)
3	6	4	0.0797	0.2509	0.157
3	6	5	0.0801	0.2181	0.167
7	8	9	0.108	0.101	0.0321
14	16	15	0.102	0.1629	0.0499
19	22	20	0.0585	0.1568	0.0906
19	22	21	0.0585	0.1568	0.0906
22	23	24	0.1273	0.0522	0.0368
22	25	26	0.0997	0.1681	0.0581
22	29	30	0.0924	0.1559	0.048
34	37	36	0.102	0.1629	0.0499
38	39	40	0.102	0.1629	0.0499
44	43	41	0.0588	0.1636	0.096
44	43	42	0.0588	0.1636	0.096
43	47	48	0.0923	0.1561	0.0475
49	50	51	0.2	0.25	0.15
52	53	54	0.2	0.25	0.15
55	56	57	0.2	0.25	0.15
34	72	73	0.102	0.1629	0.0499
17	74	75	0.102	0.162	0.05

Three-Winding Transformer

(Short Circuit Reactances)

PR Bus	SEC Bus	TER Bus	XP	XS	XT
3	6	4	0.0868	-0.0071	0.1641
3	6	5	0.0656	0.0145	0.1525
7	8	9	0.0885	0.0195	0.0125
14	16	15	0.1075	-0.0055	0.0554
19	22	20	0.0624	-0.0038	0.0944
19	22	21	0.0624	-0.0038	0.0944
22	23	24	0.0714	0.0559	-0.0192
22	25	26	0.1049	-0.0052	0.0632
22	29	30	0.1002	-0.0078	0.0558
34	37	36	0.1075	-0.0055	0.0554
38	39	40	0.1075	-0.0055	0.0554
44	43	41	0.0632	-0.0044	0.1004
44	43	42	0.0632	-0.0044	0.1004
43	47	48	0.1005	-0.0082	0.0557
49	50	51	0.15	0.05	0.1
52	53	54	0.15	0.05	0.1
55	56	57	0.15	0.05	0.1
34	72	73	0.1075	-0.0055	0.0554
17	74	75	0.107	-0.005	0.055

Three-Winding Transformer Reactances

After delta transformation

SEC	TER	x(s,t)	PR	TER	x(p,t)	PR	SEC	x(p,s)
6	4	0.14358	3	4	-1.7553	3	6	0.07594
6	5	0.20071	3	5	0.90803	3	6	0.08634
8	9	0.03475	7	9	0.15773	7	8	0.24606
16	15	0.04707	14	15	-0.9199	14	16	0.09133
22	20	0.08485	19	20	-1.3934	19	22	0.05609
22	21	0.08485	19	21	-1.3934	19	22	0.05609
23	24	0.02167	22	24	0.02768	22	23	-0.0806
25	26	0.05487	22	26	-1.1068	22	25	0.09107
29	30	0.04366	22	30	-0.5608	22	29	0.07839
37	36	0.04707	34	36	-0.9199	34	37	0.09133
39	40	0.04707	38	40	-0.9199	38	39	0.09133
43	41	0.08901	44	41	-1.2785	44	43	0.05603
43	42	0.08901	44	42	-1.2785	44	43	0.05603
47	48	0.04296	43	48	-0.5265	43	47	0.07751
50	51	0.18333	49	51	0.55	49	50	0.275
53	54	0.18333	52	54	0.55	52	53	0.275
56	57	0.18333	55	57	0.55	55	56	0.275
72	73	0.04707	34	73	-0.9199	34	72	0.09133
74	75	0.04743	17	75	-1.015	17	74	0.09227

GENERATORS' DATA

GEN.Unit	BUS No	Rated kV	Rated Mw
rosgu11	1	11	276.1
srpsg1	12	11	15
kngst3	18	11	45
kilgt	45	11	10
kukugt2	60	11	9
kukugt1	61	11	13
burold	62	11	18
burgst	63	11	15
burn1	64	11	9
burn2	65	11	9
kngt1	67	11	15
kngt2	68	11	15
kngst1	70	11	28
kngst2	71	11	28
kngst4	76	11	45

LOAD DATA

BUS NAME	LOAD(MW)
rosgu11	6.13
srj11	11.52
rbk3w11	5.5
rbk3w33	5.226
rbk2w11	6.81
mna11	10.6
mna33	2.552
mg7.5-11	2.7
mg17.5-11	5.5
mg17.5-33	7
mg15-11	6.771
mg2w7.5-11	6.6
mg12.5-11	2.2
mg12.5-33	4.3
gdf110	17.534
hasa2w-11	6.6
hasa11	5.319
hasa33	10
bagr110	5
bagr33	8.152
kilx11	5.2
kilx33	8.768
mgrs33	28.4
mgrs11	11.055
frst33	11.319
frst11	10.6
omd33	32.037
omd11	11.8
kuku33	27.687
kn33	30.687
bur33	52.6
Hglla-33	0.7
hglla-11	0.7
burtx3-11	12.1
burtx4-11	2.3

MEASURED LINES

Line No	STRT	END	Reactance
1	1	2	0.033
2	2	3	0.095
3	3	19	0.0362
4	19	44	0.073
5	6	7	0.334
6	6	11	0.0348
7	11	14	0.2213
8	17	22	0.122
9	22	31	0.242
10	31	32	0.494
11	34	38	0.278
12	38	43	0.139
13	43	49	0.024
14	52	55	0.024
15	58	13	0.0048
16	47	69	0.474
17	59	66	0.0855
18	59	69	0.01
19	55	13	0.0645
20	7	10	0.10005
21	11	12	0.1118
22	22	27	0.10005
23	22	28	0.09225
24	31	33	0.10005
25	34	35	0.09225
26	47	45	0.07708
27	47	46	0.111
28	59	60	0.132
29	59	61	0.093
30	69	62	0.11165
31	69	63	0.09105
32	69	64	0.11165
33	69	65	0.11165
34	66	67	0.115
35	66	68	0.115
36	13	66	0.093
37	13	70	0.12288

38	13	71	0.12288
39	13	18	0.11925
40	13	76	0.11925
41	69	77	0.02525
42	69	78	0.02525
43	6	4	0.1435771
44	6	5	0.2007081
45	8	9	0.0347542
46	16	15	0.0470656
47	22	20	0.0848513
48	22	21	0.0848513
49	23	24	0.0216681
50	25	26	0.0548671
51	29	30	0.0436563
52	37	36	0.0470656
53	39	40	0.0470656
54	43	41	0.0890101
55	43	42	0.0890101
56	47	48	0.0429553
57	72	73	0.0470656
58	74	75	0.0474299
59	3	5	0.908031
60	22	24	0.0276762
61	49	51	0.55
62	52	54	0.55
63	55	57	0.55
64	3	6	0.0404041
65	7	8	0.24606
66	14	16	0.0913276
67	19	22	0.0280441
68	22	25	0.091069
69	22	29	0.0783935
70	34	37	0.0913276
71	38	39	0.0913276
72	44	43	0.0280151
73	43	47	0.0775047
74	49	50	0.275
75	52	53	0.275
76	55	56	0.275
77	34	72	0.0913276
78	17	74	0.0922727

NON-MEASURED LINES

Line No	STRT	END	Reactance
1	11	17	0.209
2	22	34	0.191
3	49	52	0.024
4	43	58	0.023
5	58	59	0.093
6	50	51	0.1833333
7	53	54	0.1833333
8	56	57	0.1833333
9	3	4	-1.755
10	7	9	0.1577308
11	14	15	-0.919918
12	19	20	-1.393347
13	19	21	-1.393347
14	22	26	-1.106838
15	22	30	-0.560815
16	34	36	-0.919918
17	38	40	-0.919918
18	44	41	-1.278509
19	44	42	-1.278509
20	43	48	-0.526465
21	34	73	-0.919918
22	17	75	-1.015
23	22	23	-0.080578

APPENDIX (B)

MATLAB PROGRAMS

(A) DATA FILES

The Data files are two: the first one is called datangn.m and consists of NG data, the second is called DATANGMTR.m, and consists of the state estimator data.

(1) datangn.m

```
max=78;%Total number of bus

i=xlsread('data.xls','Start');

j=xlsread('data.xls','End');

q=xlsread('data.xls','React');

x=sparse(i,j,q,78,78,202);%Reactance matrix

S=xlsread('data.xls','MW');

B=1;%slack bus

Bb=100;%base power

g=18;%shifted generator

D=-10;%the shifted generation value

n=6;%line outaged starting bus

m=11;%line outaged ending bus
```

(2) DATANGMTR.m

```
i1=xlsread('datest.xls','strtmtr');

j1=xlsread('datest.xls','endmtr');

x1=xlsread('datest.xls','x');

H1=x1. ^-1;

Hs=sparse(i1,j1,H1,78,78);%[H] matrix

H=full(Hs);

H(:,1)=[];

Bb=100;

Q=sparse(eye(78))/Bb;R=(Q.^2);

i2=xlsread('datest.xls','i');

j2=xlsread('datest.xls','j');

xij=xlsread('datest.xls','xij');

x=sparse(i2,j2,xij,74,78);%Reactance matrix

n=78;%No.of busbars(Max ending bus).

f=74;%Max starting bus

M=xlsread('datest.xls','mtr1');
```

(B) MAIN PROGRAM

NGMTR.m

```
datangn;
N=max;
P=S./Bb;
for i=1:N
   for j=1:N
          if x(i,j)==0;
          Y(i,j)=0;
        elseif i~=j;
           Y(i,j)=-1/x(i,j);
        end
     end
     Y(i,i)=0;
     for k=1:N
        if k~=i;
           Y(i,i)=Y(i,i)-Y(i,k);
        end
    end
 end
Y(:,B)=[]; Y(B,:)=[];P(B,:)=[];
X=inv(Y);
C=X*P;
t=[0;C];
for i=1:N;
    for j=1:N;
        if x(i,j)==0;
           S(i,j)=0;
           elseif i~=j;
               S(i,j)=(t(i)-t(j))/x(i,j);
         end
      end
end
 s=sparse(S)*Bb;
 XR(1:77)=zeros;
 X=[XR;X];
 XV(1:78)=zeros;
 X=[XV' X];
 D=D/Bb;
 for i=1:N
    for j=1:N
       if x(i,j)==0
          a(i,j)=0;
       else
          a(i,j)=(X(i,g)-X(j,g))/x(i,j);
          f(i,j)=a(i,j)*D+S(i,j);
       end
    end
 end
 A=(a);
 I=S(6,11);
 for i=1:N
    for j=1:N
       if x(i,j)==0
          d(i,j)=0;
       else
        d(i,j)=(((X(i,n)-X(i,m))-(X(j,n)-X(j,m)))*x(n,m)/(x(i,j)*(x(n,m)-(X(n,n)+X(m,m)-2*X(n,m)))));
```

```
        F(i,j)=d(i,j)*l+S(i,j);
end
       d(n,m)=0;d(m,n)=0;
       if d(n,m)==0;d(m,n)==0;
          F(n,m)=0; F(m,n)=0;
       end
   end
end
d=(d);
 for i=1:N
    for j=1:N
       if S(i,j)==-S(j,i);f(i,j)==-f(j,i);F(i,j)==-F(j,i);
          S(j,i)=0;f(j,i)=0; F(j,i)=0;
       end
    end
 end
 ab='power flow at lines';
 s=sparse(S)*Bb;
 disp(ab)
 disp(s)
 D=D*Bb ;
 bc=' generation shifted value';
 disp(bc)
 disp(D)
 f=sparse(f)*Bb;
 cd='power flow after the generation shift';
 disp(cd)
 disp(f)
 L='outaged line flow';
 l=s(6,11);
 disp(L)
 disp(l)
 e='power flow after an outage of line';
 F=sparse(F)*Bb;
 disp(e)
 disp(F)

   DATANGMTR;
M=M/Bb;% Meters reading
 Xm=((H'*(R^-1)*H)^-1)*(H'*(R^-1)*M);%M is the measured values Vector.
 Xm=sparse(Xm);
 Xm=[0;Xm];
 a='bus angle value';
 disp(a)
 disp(Xm)
 for i=1:f; %the biggest starting bus.

    for j=1:n; %the biggest ending bus.

       if x(i,j)==0;
            SV(i,j)=0;
        elseif i~=j;
            SV(i,j)=(Xm(i)-Xm(j))/x(i,j);
         end
      end
  end
 b='state estimator Result';
 disp(b)
 SV=sparse(SV)*Bb;
 disp(SV)
```

APPENDIX (C)

DC SENSITIVITY ANALYSIS THEORY

CALCULATION OF NETWORK SENSITIVITY FACTORS

(I) Generation Shift Factor:

recall that the d.c power flow equation was

$$[p]=[B`] .[\theta] \qquad \text{(C-1)}$$

Since the system is linear: -

$$[\Delta p]=[B`].[\Delta\theta] \qquad \text{(C-2)}$$

$$[\Delta\theta]=[X].[\Delta p] \qquad \text{(C-3)}$$

$$a_{l\,i} = \Delta f_l/\Delta p_i\,. \qquad \text{(C-4)}$$

$$\Delta f_l = \Delta(\theta_n - \theta_m)/x_l \qquad \text{(C-5)}$$

Where

l is line between bus n&m

x_l is the line reactance

$$a_{l\,i} = (1/x_l)(\Delta\theta_n/\Delta p_i - \Delta\theta_m/\Delta p_i) \qquad \text{(C-6)}$$

Now

$$\Delta\theta_n / \Delta p_i = X_{n\,i} \qquad \text{(C-7)}$$

$$\Delta\theta_m / \Delta p_i = X_{m\,i} \qquad \text{(C-8)}$$

So

$$a_{l\,i} = (1/x_l).(X_{n\,i} - X_{m\,i}) \qquad \text{(2A-9)}$$

(II) Line Outage Distribution Factor:

A line outage may be modeled by adding two power injections to a system, one at each end of the line to be dropped.the line is actually left in the system and the effects of its being dropped are modeled by injections.Suppose line k from bus n to bus m were opened by circuit breakers. Note that when the circuit breaker are opened, no current flows through them and the line is compeletely isolated from the remainder of the network, the breakers are still closed but injections Δpn and Δpm have been added to bus n and bus m, respectively. If Δp^n = p^nmwhere

$\hat{p}_{nm}$is equal to the power flowing over the line, and $\Delta p_m = -\hat{p}_{nm}$,we will still have no current flowing through the circuit breakers even though they are closed. As far as the remainder of the network is concerned, the line is disconnected.

Using Eq.(C-3)relating to $\Delta\theta$ and Δp we have

$$\Delta\theta = [X] \quad \Delta p$$

Where

$$\Delta p = \begin{bmatrix} . \\ . \\ \Delta p_n \\ . \\ . \\ \Delta p_m \end{bmatrix}$$

So that

$$\begin{aligned} \Delta\theta_n &= X_{nn}\,\Delta p_n + X_{nm}\,\Delta p_m \\ \Delta\theta_m &= X_{mn}\,\Delta p_n + X_{mm}\,\Delta p_m \end{aligned} \qquad \text{(C-10)}$$

Define

θ_n, θ_m, p_{nm} to exist before the outage, where pnm is the flow on line k from bus n to bus m.

$\Delta\theta_n$, $\Delta\theta_m$, Δp_{nm} to be internal changes resulting from the outage.

$\hat{\theta}_n$, $\hat{\theta}_m$, $\hat{p}_{nm}$ to exist after the outage.

The outage modeling criteria requires that the incremental injections Δp_n and Δp_m equal the power flowing over the outaged line after the injections are imposed. Then if we let the line reactance be x_k.

$$\hat{p}_{nm} = \Delta p_n = -\Delta p_m \qquad \text{(C-11)}$$

where

$$p\hat{}_{nm} =(1/x_k)(\theta\hat{}_n- \theta\hat{}_m)$$

then

$$\Delta\theta_n \ = (X_{nn} -X_{nm})\ \Delta p_n$$

(C-12)

$$\Delta\theta_m \ = (X_{mm} -X_{mn})\ \Delta p_n$$

And

$$\theta\hat{}_n = \theta_n + \Delta\theta_n$$

(C-13)

$$\theta\hat{}_m = \theta_m +\Delta\theta_m$$

giving

$$p\hat{}_{nm}= (1/x_k)\ (\theta\hat{}_n- \theta\hat{}_m) = (1/x_k)\ (\theta_n- \theta_m)+(1/x_k)\ (\Delta\theta_n- \Delta\theta_m)$$

or (C-14)

$$p\hat{}_{nm}= p_{nm} +(1/x_k)(x_{nn} + x_{mm}-2x_{nm})\ \Delta p_n$$

Then (using the fact that $p\hat{}_{nm}$ is set to Δp_n)

$$\Delta p_n = [1/(1-((1/x_k)\ (X_{nn}+X_{mm} - 2X_{nm})))]\ p_{nm} \quad \text{(C-15)}$$

Define a sensitivity factor δ as the ratio of the phase angle θ, any where in the system, to the original power pnm flowing over a line nm before it was dropped. That is,

$$\delta_{i,\ nm} = \Delta\theta_i/p_{nm} \quad \text{(C-16)}$$

if neither n or m is the system reference bus, two injections, Δp_n and Δp_m, are imposed at buses n and m, respectively. This gives achange in phase angle at bus i equal to

$$\Delta\theta_i=X_{in}\ \Delta p_n + X_{im}\ \Delta p_m \quad \text{(C-17)}$$

Then using the relationship between Δp_n and Δp_m, the resulting δ factor is

$$\delta_{i,\ nm} = (X_{in} - X_{im})\ x_k / ((x_k)-(X_{nn}+X_{mm} - 2\ X_{nm})) \quad \text{(C-18)}$$

if either n or m is the reference bus, only one injection is made . The resulting δ factors are

$$\delta_{i,\,nm} = X_{in}\;x_k / (\,x_k - X_{nn}) \qquad \text{for } m = \text{reference}$$

(C-19)

$$\delta_{i,\,nm} = -X_{im}\;x_k / (\,x_k - X_{mm}) \qquad \text{for } n = \text{reference}$$

if bus i itself is the reference bus, then $\delta_{i,\,nm} = 0$ since the reference bus angle is constant.

The expression for $d_{l,k}$ is

$$\begin{aligned} d_{l,k} &= \Delta f_l / f_k o = (1/x_l)(\,\Delta\theta_i - \Delta\theta_j)/f_k o \\ &= (1/x_l)((\,\Delta\theta_i/p_{nm}) - (\Delta\theta_j/p_{nm}) \\ &= (1/x_l)(\,\delta_{i,nm} - \delta_{j,nm}\,) \end{aligned} \qquad \text{(C-20)}$$

if neither i nor j is a reference bus

$$d_{l,k} = (1/x_l)[(X_{in} - X_{im})x_k - (X_{jn} - X_{jm})x_k]/[x_k - (X_{nn} + X_{mm} - 2X_{nm})]$$

$$d_{l,k} = (x_k/x_l)[X_{in} - X_{jn} - X_{im} + X_{jm}]/[x_k - (X_{nn} + X_{mm} - 2X_{nm})] \qquad \text{(C-21)}$$

---

[1]

APPENDIX (D)

STATE ESTIMATION THEORY

MAXIMUM LIKELIHOOD CONCEPTS

Let Z^{meas} be the value of a measurement from a transducer.

Let Z^{true} be the true value of the quantity being measured.

Let η be the random error associated with the measurement then the measured value can be represented as:

$$Z^{meas} = Z^{true} + \eta \qquad \text{(D-1)}$$

Assuming error to be un biased, its probability density function is usually chosen as a normal distribution with zero mean.

Thus:

$$PDF(\eta) = (1/\sigma\sqrt{2\Pi})\exp(-\eta^2/2\sigma^2) \qquad \text{(D-2)}$$

Where

σ the standard deviation.

σ^2 the variance of the random number.

PDF(η) describes the behaviour of η, it`s plot is shown in the figure below, fig(D-1).

The standard deviation provides away to model the seriousness of the random measurement error. If σ is large, the measurement is relatively inaccurate (i.e., a poor-quality measurement device), where as a small value of σ denotes a small error spread (i.e., a higher quality measurement device).

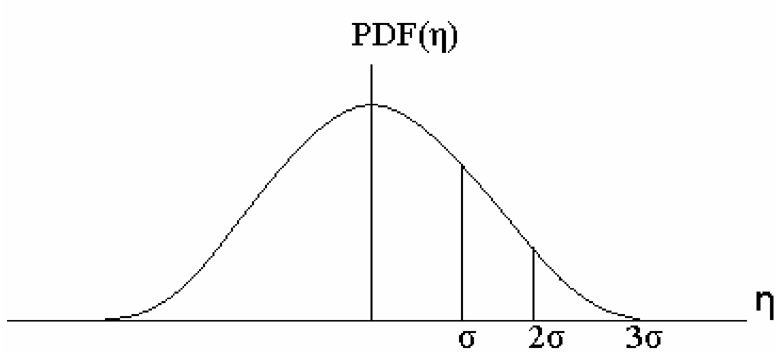


Fig (D.1)
The Normal Distribution

Since the mean value of η is zero, then the mean value of Z^{meas} is equal to Z^{true} so the probability density function for Zmeas is:

$$PDF(\eta) = (1/\sigma \sqrt{2\Pi}) \exp [-(Z^{meas}-Z^{true})^2 /2\sigma^2] \qquad (D-3)$$

From the definition of a maximum likelihood estimator there would be an estimate that maximizes the probability that the observed measurement Z^{meas} would occur so

$$Prob (Z^{meas}) = \int PDF (Z^{meas}) \, d Z^{meas} \qquad (D-4)$$

From (Z^{meas}) to $(Z^{meas} + d Z^{meas})$ as $d Z^{meas} \rightarrow 0$

Maximizing the value of Prob (Z^{meas});

$$Max\ Prob (Z^{meas}) = max\ PDF (Z^{meas}) \, d Z^{meas} \qquad (D-5)$$

$$Max\ Prob (Z^{meas}) = max\ \ln [PDF (Z^{meas})] \qquad (D-6)$$

$$Max\ Prob (Z^{meas}) = max\ [- \ln (\sigma 1 \sqrt{2\Pi}) - [(Z^{meas}-Z^{true})^2 /2\sigma^2]] \qquad (D-7)$$

Minimizing the second term since it has a negative coefficient can maximize the function in brackets.

That is

$$Max\ Prob (Z^{meas}) = min\ [(Z^{meas}-Z^{true})^2 /2\sigma^2] \qquad (D-8)$$

The value of variables that minimizes the right hand term is found by simply taking the first derivative and setting the result to zero.

[Z^{true} is function of a variable x]

Estimating a single parameter, x, using N m measurements, the expression would be written as:

$$\text{Min } J(x) = \sum_{i=1}^{Nm} [Z_i^{meas} - f_i(x)]^2 / \sigma_i^2 \qquad \text{(D-9)}$$

Where

f_i = function that is used to calculate the value being measured by the i^{th} measurement.

σ_i^2 : variance for the i^{th} measurement.

J (x): measurement residual.

N m: number of independent measurements.

Z_i^{meas}: i^{th} measurted quantity.

Estimating Ns unknown parameter using Nm measurements;

$$\text{Min } J(x_1, x_2, \ldots, x_{Ns}) = \sum_{i=1}^{Nm} [Z_i - f_i(x_1, x_2, \ldots, x_{Ns})]^2 / \sigma_i^2 \qquad \text{(D-10)}$$

The estimation calculation shown in the last tow equation above is equivalent to a maximum likelihood estimator if the measurement errors are modeled as random numbers having a normal distribution.

Matrix Formulation

Let $f_i(x_1, x_2, \ldots, x_{Ns})$ be a linear function of x so:

$$f_i(x_1, x_2, \ldots, x_{Ns}) = f_i(x) = h_{i1} x_1 + h_{i2} x_2 + \ldots + h_{iNs} x_{Ns} \qquad \text{(D-11)}$$

Placing all the fi functions in a vector:

$$f(x) = \begin{pmatrix} f_1(x) \\ f_2(x) \\ f_3(x) \end{pmatrix} = [H] \cdot x \qquad \text{(D-12)}$$

Where

[H]: an N m by Ns matrix containing the coefficients of the linear function $f_i(x)$.

N_m: number of measurements.

N_s: number of unknown parameter being estimated.

$$Z^{meas} = \begin{pmatrix} Z_1^{meas} \\ Z_2^{meas} \\ . \\ . \\ Z_{Nm}^{meas} \end{pmatrix} \qquad \text{(D-13)}$$

Then equation (D-10) can be written as:

$$\text{Min } J(x) = [Z^{meas} - f(x)]^T [R^{-1}] [Z^{meas} - f(x)] \qquad \text{(D-14)}$$

[R] Is called the covariance matrix of measurement errors, and equal to: -

$$R = \begin{pmatrix} \sigma_1^2 & & & & \\ & \sigma_2^2 & & & \\ & & . & & \\ & & & . & \\ & & & & \sigma_{Nm}^2 \end{pmatrix}$$

to obtain the general expression for the minimum in equation (D-14) expand the expression and substitute [H]x for f(x) from equation (D-12)

$$\text{Min } J(x) = \{Z^{meas\,T}\ [R^{-1}]\ Z^{meas} - x^{T}[H]^{T}\ [R^{-1}]\ Z^{meas} - Z^{meas\,T}\ [R^{-1}]\ [H]\ x + x^{T}[H]^{T}\ [R^{-1}]\ [H]\ x\} \qquad \text{(D-15)}$$

The minimum of J (x) is found when

$$\partial J(x)/\partial x_i = 0$$

For $i=1,\ldots, N_s$

This is identical to stating that the gradient of J (x), $\Delta J(x)$, is exactly zeroed.

The gradient of J (x) is

$$\Delta J(x) = -2\,[H]^{T}\ [R^{-1}]\ Z^{meas} + 2[H]^{T}\ [R^{-1}]\ [H]\ x \qquad \text{(D-16)}$$

Then $\Delta J(x) = 0$ gives

$$X^{est} = [[H]^{T}\ [R^{-1}]\ [H]]^{-1}.\ [H]^{T}\ [R^{-1}]\ Z^{meas} \qquad \text{(D-17)}$$

Derivation of least squares equations

One is often confronted with problems wherein data have been obtained by making measurements or taking samples on a process. Further more, the quantities being measured are themselves functions of other variables that we wish to estimate. These other variables will be called the state variables and designated x, where the number of the state variables as Ns. The measurement values will be called z. we will assume there that the process we are interested in can be modeled using a linear model. Then we say that each measurement Z_i is a linear function of the states xi; that is,

$$Z_i = h_i(x) = h_{i1}x_1 + h_{i2}\,x_2 + \ldots + h_{i\,Ns}\,x_{Ns} \text{ (D-18)}$$

We can also write this equation as a vector equation if we place the h_{ij} coefficients into a vector h; that is,

$$h_i = \begin{pmatrix} h_{i1} \\ h_{i2} \\ . \\ . \\ . \\ h_{i\,Ns} \end{pmatrix} \qquad (D\text{-}19).$$

Then Eq.(D-18) becomes

$$z_i = h_i^T . x \qquad (D\text{-}20)$$

Where

$$x = \begin{pmatrix} x_1 \\ x_2 \\ . \\ . \\ . \\ x_{Ns} \end{pmatrix}$$

Finally, we can write all the measurement equations in a compact form

$$z = [H]\, x \qquad (D\text{-}21).$$

Where

$$z = \begin{pmatrix} z_1 \\ z_2 \\ . \\ . \\ . \\ z_{Nm} \end{pmatrix}$$

$$
H = \begin{pmatrix} h_{11} & h_{12} & \dots & h_{1Ns} \\ h_{21} & h_{22} & \dots & h_{2Ns} \\ . & & & \\ . & & & \\ . & & & \\ h_{31} & h_{32} & \dots & h_{Nm\,Ns} \end{pmatrix}
$$

Where row i of [H] is equal to vector h_i^T.

With Nm measurements we can have three possible cases to solve.

The Over Determined Case (Nm>Ns)

In this case, we have more measurements or samples than state variables; therefore, we can write more equations, h_i (x), than we have unknowns' x_j. One way to estimate the xi values is to minimize the sum of the squares of difference between the measurement values z_i and the estimate of z_i that is, in turn, a function of the estimates of x_i. That is, we wish to minimize

$$J(x) = \sum_{i=1}^{Nm} [Z_i - h_i (x_1, x_2, \dots, x_{Ns})]^2 \qquad \text{(D-22)}$$

It can be written as

$$J(x) = \sum_{i=1}^{Nm} (Z_i - h_i^T x)^2 \qquad \text{(D-23)}$$

And this can be written in a still more compact form as

$$J(x) = (z - [H]\,x)^T (z - [H]\,x) \qquad \text{(D-24)}$$

If we wish to find the value of x that minimizes J(x),we can take the first derivative of J(x)with respect to each x_j(j = 1,…,Ns) and set these derivatives to zero. That is,

$$\partial J(x) / \partial x_i = 0 \qquad \text{for } i=1,\dots, Ns \qquad \text{(D-25).}$$

If we place these derivative into a vector, we have what is called the gradient of J (x), which is written $\nabla_x J(x)$. Then,

$$\nabla_x J(x) = \begin{pmatrix} \partial J(x)/\partial x_1 \\ \partial J(x)/\partial x_2 \\ . \\ . \\ . \end{pmatrix} \qquad \text{(D-26)}$$

Then the goal of forcing each derivative to zero can be written as

$$\nabla_X J(x) = 0 \qquad \text{(D-27)}$$

Where 0 is a vector of Ns elements, each of which is zero. To solve this problem we will first expand Eq. (D-24)

$$J(x) = (z - [H]x)^T (z - [H]x)$$
$$= z^T z - x^T [H]^T z - z^T [H] x + x^T [H]^T [H] x \qquad \text{(D-28)}$$

The second and third term in Eq (D-28) are identical, so that we can write

$$J(x) = z^T z - 2z^T [H] x + x^T [H]^T [H] x \qquad \text{(D-29)}$$

Before proceeding, we will derive a few simple relationships. The gradient is always a vector of first derivatives of a scalar function, then its gradient $\nabla_y F$ is:

$$\nabla_y F \quad \begin{pmatrix} \partial F/\partial y_1 \\ \partial F/\partial y_2 \\ . \\ . \\ . \\ \partial F/\partial y_3 \end{pmatrix} \qquad \text{(D-30)}$$

Then if we defined F as follows:

$$F = y^T b = \begin{bmatrix} y_1 & y_2 & \ldots \end{bmatrix} \begin{pmatrix} b_1 \\ b_2 \\ \cdot \\ \cdot \\ b_n \end{pmatrix} \qquad \text{(D-31)}$$

Where b is a vector of constants b_i, $i=1,\ldots, n$, then, F can be expanded as

$$F= y_1b_1+y_2b_2+y_3b_3+\ldots \qquad \text{(D-32)}$$

and the gradient of F is

$$\nabla_y F = \begin{pmatrix} \partial F/\partial y_1 \\ \partial F/\partial y_2 \\ \cdot \\ \cdot \\ \cdot \\ \partial F/\partial y_n \end{pmatrix} = \begin{pmatrix} b_1 \\ b_2 \\ \cdot \\ \cdot \\ \cdot \\ b_n \end{pmatrix} = b \qquad \text{(D-33)}$$

It ought to be obvious that writing F with y and b reversed makes no difference. That is,

$$F = b^T y = y^T b \qquad \text{(D-34)}$$

And therefore, $\nabla_y b^T y = b$.

Suppose we now write the vector b as the product of a matrix [A] and a vector u.

$$b=[A]\, u \qquad \text{(D-35).}$$

Then if we take F as shown in Eq. (D-31)

$$F = y^T b = y^T[A]\, u \qquad \text{(D-36).}$$

We can say that

$$_{y}\nabla F = [A]\, u \qquad \text{(D-37).}$$

Similarly we can define

$$b^T = u^T [A] \qquad \text{(D-38).}$$

If we can take F as shown in Eq . (D-36)

$$F = b^T y = u^T [A]\, y$$

Then

$$_{Y}\nabla F = [A]^T u \qquad \text{(D-39).}$$

Finally we will look at a scalar function F that is quadratic namely,

$$F = y^T [A]\, y$$

$$= [y_1\; y_2 \ldots y_n] \begin{pmatrix} a_{11} & a_{12} & \ldots \\ a_{21} & a_{22} & \ldots \\ . & . & \\ . & . & \\ . & . & \end{pmatrix} \begin{pmatrix} y_1 \\ y_2 \\ . \\ . \\ y_n \end{pmatrix} \qquad \text{(D-40).}$$

$$= \sum_{i=1}^{n} \sum_{j=1}^{n} y_i\, a_{ij}\, y_j \qquad \text{(D-41).}$$

Then

$$\nabla_y \mathbf{F} = \begin{pmatrix} \partial \mathbf{F} / \partial \mathbf{y_1} \\ \partial \mathbf{F} / \partial \mathbf{y_2} \\ . \\ . \\ . \\ \partial \mathbf{F} / \partial \mathbf{y_n} \end{pmatrix} = \begin{pmatrix} \mathbf{2\, a_{11}\, y_1 + 2\, a_{12}\, y_2 + \ldots} \\ \mathbf{2\, a_{21}\, y_2 + 2\, a_{22}\, y_2 + \ldots} \\ . \quad . \quad . \\ . \quad . \quad . \end{pmatrix} = \mathbf{2\, [A]\, y} \qquad \textbf{(D-42)}$$

Then, in summary:

$$\boxed{\begin{array}{lll} 1.\ F = y^T b & \nabla_y F = b \\ 2.\ F = b^T y & \nabla_y F = b \\ 3.\ F = y^T [A] u & \nabla_y F = [A] u \\ 4.\ F = u^T [A] y & \nabla_Y F = [A]^T u \\ 5.\ F = y^T [A] y & \nabla_Y F = 2 [A] y \end{array}} \qquad \text{(D-43)}$$

We will now use Eq. (D-43) to derive the gradient of J(x), that is $\nabla_x J$, where J(x) is shown in Eq. (D-30). The first term, $z^T z$ is not a function of x, so we can discard it. The second term is of the same form as (4) in Eq. (D-43), so that,

$$\nabla_x (-2z^T [H] x) = -2[H]^T z \qquad \text{(D-44)}$$

The third term is the same as (5) in Eq. (D-43) with $[H]^T [H]$ replacing [A]; then,

$$\nabla_x (x^T [H] [H]^T x) = 2[H]^T [H]x \qquad \text{(D-45).}$$

Then from Eqs. (D-44) and (D-45) we have

$$\nabla_x J = -2 [H]^T z + 2[H]^T [H]x \qquad \text{(D-46).}$$

But, as stated in Eq.(D-27) we wish to force $\nabla_x J$ to zero

$$-2[H]^T z + 2[H]^T [H] x = 0$$

Or

$$x = [[H]^T[H]]^{-1} [H]^T z \qquad \text{(D-47).}$$

If we had wanted to put a different weight, w_i, on each measurement, we could have written Eq.(3A-23) as

$$J(x) = \sum_{i=1}^{Nm} w_i (z_i - h_i^T x)^2 \qquad \text{(D-48).}$$

Which can be written as

$$J(x) = (z- [H] x)^T [W] (z- [H] x)$$

Where [W] is a diagonal matrix, then

$$J(x) = z^T[W]\, z - x^T[H]^T[W]z - z^T[W][H]\, x + x^T[H]^T[W][H]x$$

If we once again using Eq. (D-43) we would obtain

$$\nabla_x J = -\,2[H]^T\,[W]\,z + 2[H]^T[W]\,[H]x$$

And

$$\nabla_x J = 0$$

Gives

$$x = ([H]^T[W][H])^{-1}\,[H]^T[W]z \qquad \text{(D-49)}$$

The Fully-Determined Case (Nm =Ns)

In this case, the number of measurements is equal to the number of state variables and we can solve for x directly by inverting [H].

$$X = [H]^{-1}z \qquad \text{(D-50)}$$

The Underdetermined Case (Nm < Ns)

In this case, we have fewer measurements than state variables. In such a case, it is possible to solve for many solutions x^{est} that cause J (x) to equal zero. The usual solution technique is to find x^{est} that minimizes the sum of squares of the solution values. That is, we find a solution such that

$$\sum_{j=1}^{Ns} x_j^{\,2} \qquad \text{(D-51).}$$

is minimized while meeting the condition that the measurements will be solved for exactly. To do this, we treat the problem as a constrained minimization problem and use Lagrange multipliers.

We formulate the problem as

Minimize $$\sum_{j=1}^{Ns} x_j^{\,2}$$

(D-52)

subject to

$$z_i = \sum_{j=1}^{Ns} h_{ij}\, x_j \qquad \text{for } i = 1,\ldots,N_m$$

This optimization problem can be written in a vector-matrix form as

$$\text{Min } x^T x$$

Subject to $$z=[H]x \qquad \text{(D-53)}$$

The Lagrangian for this problem is

$$L = x^T x + \lambda^T (z-[H]\, x) \qquad \text{(D-54)}$$

we must find the gradient of L with respect to x and λ. Using the identities found in Eq. (3A-43) we get,

$$\nabla_{\lambda} L = 2x - [H]^T \lambda = 0$$

which gives

$$x=(1/2)\, [H]^T \lambda$$

and

$$\nabla_{\lambda} L = z - [H]\, x = 0$$

which gives

$$z = [H]\, x$$

Then

$$z=(1/2)[H]\, [H]^T \lambda$$

or

$$\lambda = 2[[H]\, [H]^T]^{-1} z$$

and finally

$$x = [H]^T\, [[H]\, [H]^T]^{-1} z \qquad \text{(D-55)}$$

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[1]

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